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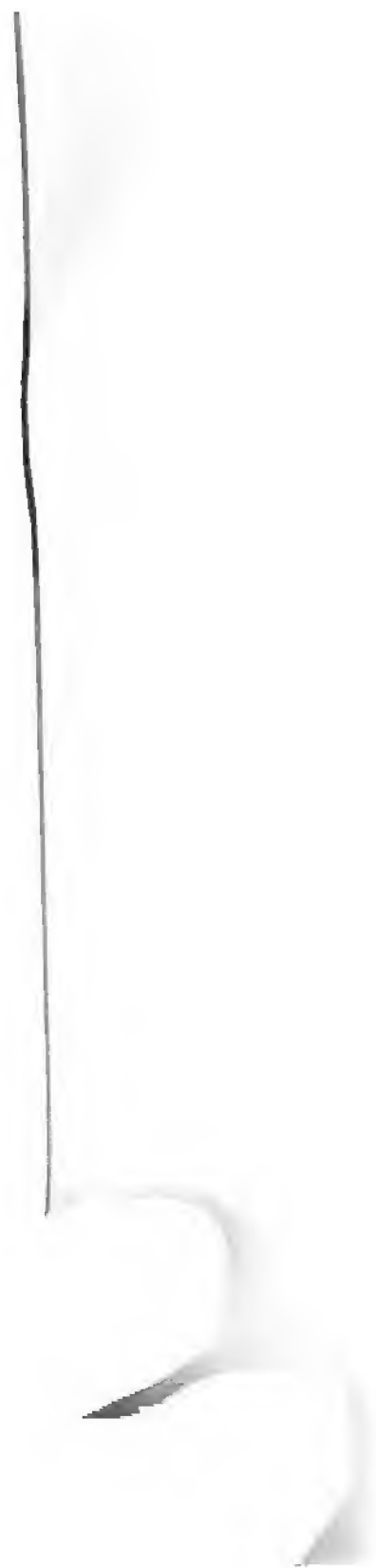


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BULLETIN 526

COASTAL GLACIERS
OF
PRINCE WILLIAM SOUND AND
KENAI PENINSULA
ALASKA

BY

U. S. GRANT AND D. F. HIGGINS



STANDARD PUBLICATION

WASHINGTON
GOVERNMENT PRINTING OFFICE
1913

65

283385

Y9A 891 09073472

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COASTAL GLACIERS OF PRINCE WILLIAM SOUND AND KENAI PENINSULA, ALASKA.

By U. S. GRANT and D. F. HIGGINS.

INTRODUCTION.

SCOPE OF THIS REPORT.

During the summer of 1905 the senior author and Sidney Paige were engaged in a study of the ore deposits and the general geology of Prince William Sound. This work was continued in 1908 for a few weeks by both the present authors, who in 1909 extended it to the southern part of Kenai Peninsula. In these three field seasons the whole shore line of Prince William Sound (except that of some of the islands) and of Kenai Peninsula from Portage Bay to Seldovia Bay of Cook Inlet was examined. In the course of this work all the tidewater glaciers and many others near tidewater were seen and some notes, photographs, and maps were made of all the tidewater glaciers and of many of the others. This work was hurriedly done and was secondary to the study of the bedrock geology and the ore deposits; nevertheless it is thought worth while to put on record the information thus obtained regarding the glaciers, for it will afford a basis for future study of the fluctuations of these ice streams.

This paper, then, is not expected to make many additions to the large amount of scientific material concerning the problems of glaciers and glaciation that is already available, but it is intended to supply some definite information regarding the present positions of the fronts of the glaciers and the more evident facts of their fluctuations. Moreover, it is hoped that this publication may attract attention to some of the most magnificent American scenery that is now accessible to the tourist and nature lover. Except the Columbia Glacier, the glaciers of Port Wells, and possibly one or two others, the ice streams here considered had not been figured nor described before this study was undertaken.

In the first season of field work, in 1905, information concerning the Valdez, Shoup, Columbia, and Meares glaciers and some of the glaciers of Port Wells was obtained. In 1908 the Valdez, Shoup, Columbia, and Barry glaciers were again visited, and the glaciers

of Port Nellie Juan, Icy Bay, and Port Bainbridge were mapped. The small glaciers above Thumb Cove of Resurrection Bay also were visited and sketched. In 1909 all the tidewater glaciers of the northern shore of Prince William Sound from Port Valdez westward to and including Blackstone Bay and all the glaciers of the southern shore of Kenai Peninsula discussed in this report, except those at the head of Thumb Cove of Resurrection Bay, were visited and mapped.

Since beginning this work the authors have prepared small-scale maps on which the positions of the fronts of a number of these glaciers are shown.¹ Most of these maps, however, are drawn on too small a scale to show in much detail the positions of these glacial fronts. Brief descriptions of some of the more important glaciers discussed in this report have been published recently.²

EARLIER EXPLORATIONS.

The earliest explorers of Prince William Sound and Kenai Peninsula gave little information concerning the glaciers; in fact, glaciers as such were not known to them. Cook³ in 1778 and especially Vancouver⁴ in 1794 explored much of the above district, and some of their maps and descriptions show that certain of the bays or fiords were ended by vertical walls of ice, from which blocks fell into the sea.

Dall⁵ visited Kachemak Bay of Cook Inlet in 1880, in 1892, and in 1895, and studied especially the Grewingk Glacier. The results of his mapping of this glacier were incorporated in charts of the United States Coast and Geodetic Survey.

The more recent explorations of this district by geologists of the United States Geological Survey were begun by Mendenhall⁶ and Schrader⁷ in 1898, but the varied interests of their expeditions allowed little attention to be paid to the glaciers.

In 1899 the Harriman Alaska Expedition visited Prince William Sound and described the Columbia Glacier and the glaciers of Port Wells. These descriptions were written by Gilbert⁸ and form the chief published source of information concerning the glaciers of

¹ Bull. U. S. Geol. Survey No. 284, 1906, p. 79; No. 379, 1909, Pl. IV, and p. 100; No. 442, 1910, Pl. III; No. 443, 1910, Pl. II.

² Grant, U. S., and Higgins, D. F., *Glaciers of Prince William Sound and the southern part of the Kenai Peninsula, Alaska*: Bull. Am. Geog. Soc., vol. 42, 1910, pp. 721-738; vol. 43, 1911, pp. 321-338, 401-417, 721-737.

³ Cook, James, *A voyage to the Pacific Ocean undertaken by the command of His Majesty for making discoveries in the northern hemisphere, etc.*, in 1776-1780, 3 vols., London, 1784.

⁴ Vancouver, George, *Voyage of discovery to the North Pacific Ocean, etc.*, in 1790-1795, 3 vols., London, 1798.

⁵ Dall, W. H., Bull. Philos. Soc., Washington, vol. 6, 1884, pp. 33-36; Bull. U. S. Geol. Survey No. 84, 1892; Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, p. 789.

⁶ Mendenhall, W. C., *A reconnaissance from Resurrection Bay to the Tanana River, Alaska*, in 1898: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 265-340.

⁷ Schrader, F. C., *A reconnaissance of a part of Prince William Sound and the Copper River district, Alaska*, in 1898: *Idem*, pp. 341-423.

⁸ Gilbert, G. K., *Glaciers and glaciation: Alaska*, vol. 3, Harriman Alaska Expedition, 1904.

Prince William Sound. No attempt has been made to duplicate these excellent descriptions in the present paper.

In 1904 Davidson¹ published a list, accompanied by notes and maps, of the coastal glaciers of Alaska. Brooks,² in his description of Alaskan geography and geology, has made mention of the glaciers of this district; Reid³ has contributed some notes on the variations of Alaskan glaciers; and Tarr and Martin⁴ studied the Valdez, Shoup, and Columbia glaciers in 1909.

MAPS OF THE GLACIERS.

Most of the older maps of Prince William Sound and Kenai Peninsula are on a scale so small and are so generalized that they furnish very little information concerning the actual positions of glacial fronts at the dates on which the maps were made. They are thus of little aid in determining historic positions of the fronts of the glaciers and could not furnish a basis for a study of glacial fluctuations unless the fluctuations amounted to several miles—a maximum not reached in historic times by the glaciers under discussion. Cook mapped Prince William Sound and Kenai Peninsula in 1778, but his map is on a very small scale. Vancouver's maps of 1794 and Tebenkof's of 1852, the latter following closely those of Vancouver, furnished the basis for most of the maps of this district up to the end of the nineteenth century. Recently the work of the United States Coast and Geodetic Survey has given accurate delineations of parts of Prince William Sound and Kenai Peninsula, but very considerable portions of the coast line have not yet been mapped by this organization. Unfortunately for our purposes, the fronts of only two tidewater glaciers, the Shoup of Port Valdez and the Bear of Resurrection Bay, have been thus mapped. The maps of the Columbia Glacier and of the glaciers of Port Wells published by the Harriman Alaska Expedition⁵ were the first to show details of these glaciers. The United States Geological Survey has issued maps showing in some detail the positions of the fronts of some of the glaciers of Prince William Sound, especially those of the Shoup and Valdez glaciers.⁶

Thus at the beginning of the present study of the glaciers of Prince William Sound and Kenai Peninsula there was available detailed information concerning only the Valdez, Shoup, Columbia, and

¹ Davidson, George, The glaciers of Alaska that are shown on Russian charts or mentioned in older narratives: *Trans. and Proc. Geog. Soc. Pacific*, 2d ser., vol. 3, 1904, pp. 1-98, 11 maps.

² Brooks, A. H., The geography and geology of Alaska: Prof. Paper U. S. Geol. Survey No. 45, 1906; especially pp. 244-245 and Pl. XXII.

³ Reid, H. F., The variations of glaciers: *Jour. Geology*, vol. 14, 1906, pp. 402-410; vol. 17, 1909, pp. 667-671.

⁴ Tarr, R. S., and Martin, Lawrence, The National Geographic Society's Alaskan expedition of 1909: *Nat. Geog. Mag.*, vol. 21, 1910, pp. 1-54.

⁵ Gilbert, G. K., Glaciers and glaciation: Alaska, vol. 3, Harriman Alaska Expedition, 1904, Pls. XI and XIII.

⁶ Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, map No. 20; The geology and mineral resources of a portion of the Copper River district, Alaska; Special publication, 1901, pl. 2.

Bear glaciers and some of the glaciers of Port Wells, and this information extended back only a few years.

In the present report Plates I and II (in pocket) show the general distribution of the glaciers of Prince William Sound and the southern part of Kenai Peninsula. More detailed information concerning these glaciers is given in a number of the other plates and figures. These maps were, with minor exceptions, made by the junior author. Some of the maps are merely sketches indicating the general relations of the glaciers to the shore line; others are more carefully made. An idea of the accuracy of these maps can be gained from noting the closeness and number of the positions that were occupied or intersected in making the maps. In this work the information obtained by the authors was usually controlled by graphic triangulation with the "baby" plane table from base lines or United States Coast and Geodetic Survey triangulation stations. The base lines were determined by the log of the boat, and in the expansions these approximately correct values were assumed to be the true values. The control was supplemented by occasional boat and foot traverses. The sketching was done from the stations and from the boat between stations. A few minor changes were made in the office from photographs.

PHOTOGRAPHS OF THE GLACIERS.

In any study of the positions of glacier fronts dated photographs are of prime importance, for they furnish accurate records and can be obtained when there is not time for detailed observations. If the photographs are taken from easily recognized stations which can be occupied in later years their value is still greater. In the present study of the glaciers of Prince William Sound and Kenai Peninsula many photographs were taken from stations shown on the several detailed maps accompanying this report. These and other photographs will be of so great value in the study of future fluctuations of these ice streams that it has been thought wise to list, under the description of each glacier (or general area), all the photographs showing that glacier or area in the collections preserved in the office of the United States Geological Survey at Washington. In these lists the following abbreviations have been used:

G: Photographs taken by U. S. Grant and D. F. Higgins, 1908-9

Gi: Photographs taken by G. K. Gilbert, 1899.

M: Photographs taken by W. C. Mendenhall, 1898.

P: Photographs taken by Sidney Paige, 1905.

Sc: Photographs taken by F. C. Schrader, 1898.

Sp: Photographs taken by A. C. Spencer, 1900.

In addition to the photographs noted above, the following have been accessible to the writers: (1) Photographs taken by C. Har Merriam and E. S. Curtis for the Harriman Alaska Expedition, 189

(2) photographs taken by W. E. Carlin for the George W. Perkins party, 1909; (3) photographs taken by R. S. Tarr and Lawrence Martin for the National Geographic Society expedition, 1909; (4) photographs taken by P. S. Hunt and G. G. Cantwell, of Valdez.

GLACIERS OF PRINCE WILLIAM SOUND.

PORT VALDEZ.

GENERAL FEATURES.

Port Valdez is the extreme northeastern fiord of Prince William Sound. The main portion of the fiord trends east and west and is about 14 miles long and 3 miles wide. Its axis is essentially parallel

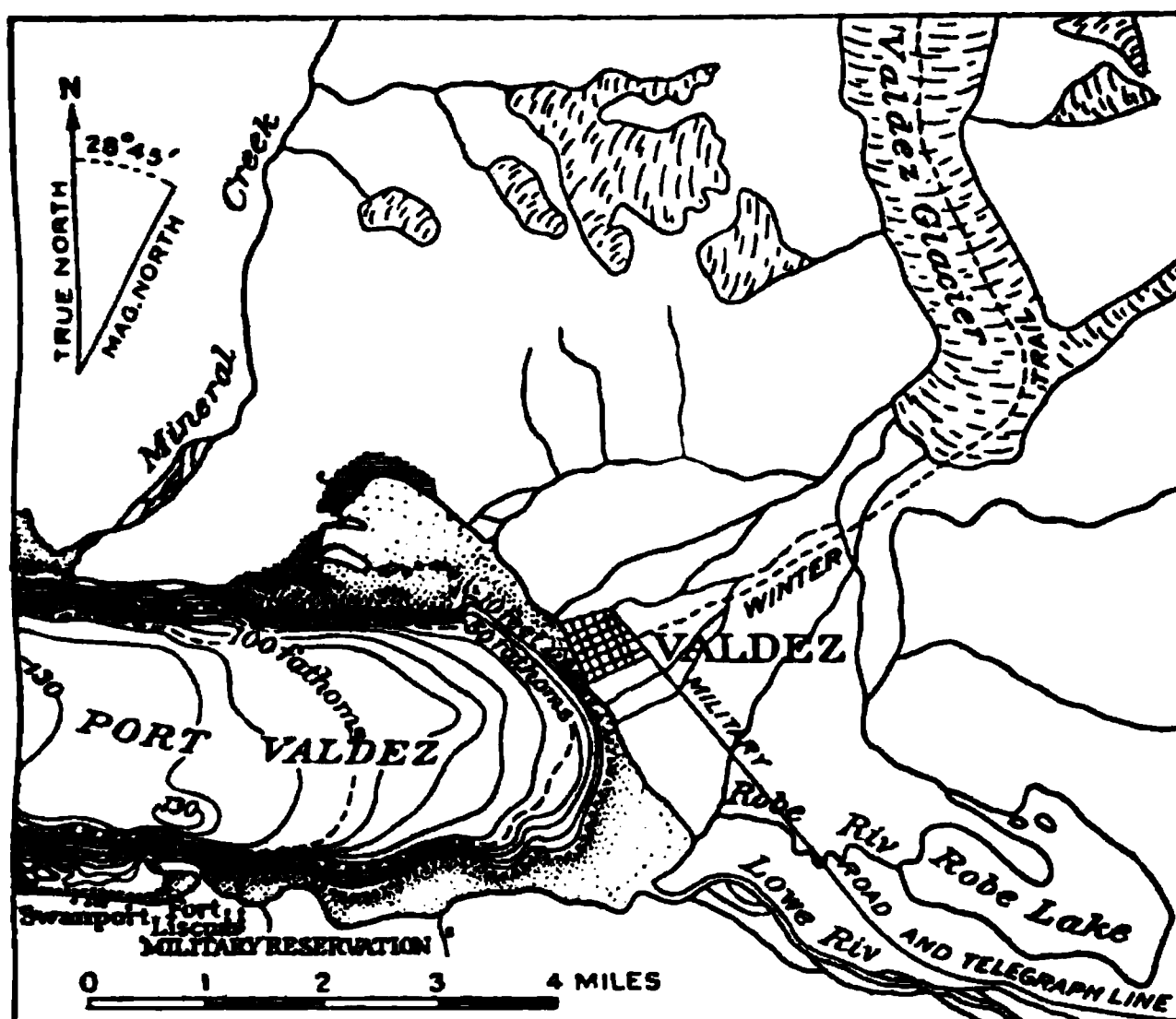


FIGURE 1.—Map of Valdez and vicinity. From maps of the United States Geological Survey and Coast and Geodetic Survey. Submarine contour interval, 10 fathoms.

with the strike of the country rocks. At its western end this portion bends abruptly to the south-southwest, narrows to a width of a mile, and cuts almost directly across the strike of the rocks. The depression in which Port Valdez lies extends northwestward in the Shoup Glacier valley, northeastward in the Valdez Glacier valley, and eastward in the valley of Lowe River. Except for these valleys, each of which is much smaller than the port itself, Port Valdez is hemmed in by steep mountains, those on the west and north being extremely steep and rising to heights of 4,000 to 5,400 feet. The mountains on the south side are 3,000 to 4,600 feet in height.

The main portion of Port Valdez is a wide, flat-bottomed trough averaging about 800 feet in depth and reaching in one place a depth

of 858 feet below sea level. The sides of this trough below sea level are uniformly steep, having a customary slope of 24° , but in one place this slope is over 51° for a vertical distance of 756 feet. (See figs. 1 and 2.) The eastern end of Port Valdez is being rapidly filled with material brought down by Lowe River and by streams from the Corbin and Valdez glaciers, most of this material coming from the latter glacier. The advancing delta thus produced has a steep submarine front, its slope being nearly 12° . The subaerial portion of the delta extends east along Lowe River, also northeast, 4 miles, to the Valdez Glacier, rising in this distance probably 250 feet. It seems quite probable that slumping is taking place occasionally along the seaward edge of the delta. On February 14, 1908, an earthquake of considerable magnitude visited this district and broke in several places both the Seattle-Valdez and the Valdez-Seward cables, which run east and west through Port Valdez. Accompanying the earthquake there seems to have been a slumping of the delta front which buried sections of the cables. The cause of the earthquake is not known, but it is thought to have been minor faulting, for one of the cables was broken in deep water on the flat bottom of the fiord 11 miles from Valdez. The slumping of the delta front at this time was therefore probably a result rather than a cause of the earthquake.

On Port Valdez there is one tidal glacier, the Shoup. The Valdez Glacier reaches within 4 miles of the port and the lower end of the Corbin Glacier lies 7 miles east of Valdez. The Valdez Glacier receives smaller ice streams from the east, but its main snow field lies on the northwest. The Shoup Glacier and probably part of the Columbia Glacier come from the same snow field. There are a few small glaciers high up in the mountains about the ends of the main portion of Port Valdez, the most noticeable of which are one (unnamed) a mile or more east of the front of the Valdez Glacier, and one 3 miles southeast of Shoup Bay, called the Annin Glacier.¹

VALDEZ GLACIER.

The Valdez Glacier (fig. 1) is situated about 4 miles northeast of the town of Valdez and is well known as one of the glacial highways of Alaska. During the spring and summer of 1898 and the early part of 1899 this glacier was used as a roadway by the host of gold seekers passing northward from Valdez into the Copper River and Yukon basins. The construction in 1899 of the military telegraph line and trail, followed in later years by the development of the trail into a wagon road, from Valdez northward over Thompson Pass into the Copper River basin has taken away the necessity for traveling

¹ Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, maps Nos. 20 and 21.



A. CENTER OF FRONT OF VALDEZ GLACIER.
Looking southeast July, 1905. Photograph P 711.



B. WEST EDGE OF FRONT OF VALDEZ GLACIER
July, 1905 Photograph P 714

over the Valdez Glacier. The front of the glacier is covered with *débris*, has a low slope, and is easy of ascent, although in 1898 within the first 500 feet of rise there were three marked benches, each about 100 feet high, over which passage was difficult. The glacier itself and the method of traveling over it have been interestingly described by Schrader.¹

A hasty visit was made to the west side of the front of the Valdez Glacier in July, 1905, and another on July 11, 1908. At these times a few notes and photographs showing the position of the edge of the ice were taken, but no map of the glacier was made.

The front of the glacier is covered with *débris* (Pls. III, *A*, and IV, *A*), and toward its center an area thus covered runs back from the front of the ice and may form part of a medial moraine, though this point was not determined. The front deploys slightly on the plain of outwash material, and it is commonly reported that the ice reaches out under this plain for a considerable distance, even to the sea, but the evidence presented for this extension of the ice is far from conclusive. The outwash plain is broad, contains many reticulated stream channels, and reaches to the sea. (See Pl. III, *B*.) These streams vary much in position and in volume. The front of the glacier is so fully exposed to the sun that a few consecutive bright summer days cause extensive melting and a consequent flooding of the streams. Such an occurrence in the summer of 1905 carried away a few small buildings from the eastern edge of Valdez, but the town is now protected from encroachments of this character by a strong cordon of piles connected by heavy planks.

Photographs of the front of the Valdez Glacier, taken in July, 1905, are shown in Plate IV. The mound from which these were taken was destroyed by an advance of the ice at some time before July, 1908, and while the glacier was extended a moraine 10 to 30 feet high and 25 to 125 feet wide was deposited 250 to 300 feet in advance of the position of the front of the ice in 1905. This moraine is a quarter of a mile in length, and its western end is about the same distance from the western rock wall of the valley. In July, 1908, the front of the glacier at the western side was about 100 feet in advance of its position in 1905, and the central part of the front was apparently a short distance less advanced than in 1905. In August, 1909, the Valdez Glacier was visited by Tarr and Martin, whose photographs show that the central and western parts were a little less advanced than they were in 1908, and that the extreme western edge was slightly less advanced than in 1905. Photographs of the glacier, taken from a distance by A. C. Spencer in June, 1900, show that the position of the glacial front on that date was not materially different from its

¹ Schrader, F. C., A reconnaissance of a part of Prince William Sound and the Copper River district, Alaska. in 1898: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 350-356, 365-366, 381-382.

positions in 1905, 1908, and 1909. There is no forest near the front of the ice, hence the present time seems to be in general a period of retreat for this glacier. The cover of low vegetation and the small extent of the bare zone on the western wall of the valley indicate that there has been no marked advance of the ice beyond its positions of 1905 and 1909 since the opening of the twentieth century.

Reid gives the following information concerning the Valdez Glacier:¹

Dr. L. S. Camicia has been keeping a record since 1901 of the position of the Valdez Glacier, Prince William Sound, Alaska. A stone monument was made on the moraine in front of the glacier and the distance to the ice determined. He found the following variations, measurements having been made in June of each year: 1901-2, a retreat of 39 feet; 1902-1904, 165 feet; 1904-5, 138 feet. The next observation was made in October, 1908; as the monument had been destroyed, he estimated its position as well as he could, and found a retreat since the last observation of 244 feet, making a total retreat from 1901 to 1908 of 586 feet.

Evidently the same advance of the ice (occurring between July, 1905, and July, 1908) that destroyed the above-mentioned monument also destroyed the mound from which our observations were made in July, 1905. The destruction of these points of reference makes it impossible to determine accurately the position of the ice front in 1908 with reference to its position three years earlier. Moreover, the fluctuation of one part of the ice front differs from that of other parts, and as our observations and those of Dr. Camicia may not have had reference to the same point in the glacier's front, it is not surprising that the two estimates of retreat from 1905 to 1908 are not in full agreement. Our estimates are based on a hurried examination of the locality in 1908 and on a study of photographs of the glacial front, some taken then and some three years before.

The maps showing the Valdez Glacier indicate that a feeder comes down the first valley on the east and joins the main stream. Our photographs show, however, that this smaller glacier ends before joining the larger stream and that another glacier comes in from the south and nearly or quite joins the small glacier just mentioned.

Photographs of Valdez Glacier.

Sc 51. Front of glacier from the west edge of the glacier, 600 feet above sea level. The low dark point in the center is the one referred to under (1) in No. G 2 below. 1898.

Sc 52 to 55. Views on glacier, back from the front. 1898.

Sc 56. Front of glacier from west edge of the glacier, looking S. 25° W. 1898.

Sc 57. Source of river at front of glacier. 1898.

Sc 59. Center of front of glacier, looking N. 50° E. 1898.

Sc 62 to 72. Views on glacier, back from the front. 1898.

Sc 194. Distant view of glacier. October 22, 1898.

Sc 195. Distant view of glacier. 1898.

Sp 7. General view of front of glacier from the southwest. June 15, 1900.

¹ Reid, H. F., The variation of glaciers: Jour. Geology, vol. 17, 1909, p. 670.

Sp 11. General view of front of glacier from the south. June 24, 1900.

P 708. Débris-covered front of glacier and outwash plain, taken from the glacier and looking toward Valdez. July, 1905.

P 709. Crevasse near front of glacier. July, 1905.

P 710. Valdez Glacier (in foreground) and smaller glaciers on east side of the Valdez (in background). July, 1905.

P 711. (Here reproduced as Plate IV, A.) Center of front of glacier, looking south-east. July, 1905.

P 711a. (Here reproduced as Plate IV, B.) Western edge of front of glacier. July, 1905.

P 734. Outwash plain, extreme eastern edge of glacier, and small hanging glacier. September 9, 1905.

G 1. General view of front of glacier from a distance of about $1\frac{1}{2}$ miles. July 11, 1908.

G 2. Center of front of glacier, looking S. 67° E. From the position from which this photograph was taken bearings are as follows: (1) S. 4° W. to outer end of rock ridge that extends into the valley for about half a mile from its east side; (2) S. 66° E. to talus slope on small stream east of glacier—this talus slope is shown just to the left of the center of this photograph and in the center of Plate IV, A; (3) S. 51° W. to outer end of rock ridge that extends into the valley for a few rods from its west side. This photograph was taken from very nearly the same position as Nos. P 711 and P 711a. From the position above described the nearest point of the ice was 530 feet distant in a direction N. 48° E., on July 11, 1908.

G 3. Western edge of front of glacier, looking N. 22° W. from same position as last. July 11, 1908.

G 4. Western edge of front of glacier, looking N. 14° E. from top of a nearly circular mound, 12 feet high, 40 feet in north-south diameter and 30 feet in east-west diameter of base. This mound is about one-fourth of a mile from the west side of the valley, and is the first prominent mound seen on approaching the glacier from the southwest. From this position bearings are as follows: (1) S. 3° E. to point (1) under No. G 2; (2) S. 73° E. to point (2) under No. G 2; (3) S. 67° W. to point (3) under No. G 2. July 11, 1908. This same position was occupied by Tarr and Martin in August, 1909.

G 5. Center of front of glacier, looking S. 72° E. from same position as No. G 4. July 11, 1908.

G 6. Detail of front of glacier, looking up first valley on east of glacier. July 11, 1908.

G 9. Eastern front of glacier from southeast end of eastern dock at Valdez. July 12, 1908.

SHOUP GLACIER.

Shoup Glacier reaches tidewater at the head of Shoup Bay, which connects with the northwestern corner of the main portion of Port Valdez. On maps published in 1900¹ this is called the Canyon Creek Glacier, but on the United States Coast and Geodetic Survey charts 8521 and 8519, published, respectively, in 1902 and 1906, it is called the Shoup Glacier, by which name it is now commonly known at Valdez and Fort Liscum. This glacier is of economic importance in that it furnishes ice for Valdez and Fort Liscum, the detached bergs being lifted upon barges and taken to these towns.

Shoup Glacier was visited and photographed on July 4, 1905, July 13, 1908, and June 16, 1909, and its front was mapped on the

¹ Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, maps Nos. 19, 20, 21. Report on Public Resolution No. 25, Fifty-fifth Congress, 2d session, map 7.

16 GLACIERS OF PRINCE WILLIAM SOUND AND KENAI PENINSULA.

last date. (See Pl. V and fig. 2.) The record of the position of the front of the glacier before 1905 is confusing. The first three of the maps made in 1898 (published in 1900 and noted above) show the ice front as reaching tidewater close behind the spit at the mouth of Shoup Bay, whereas the other map indicates that the glacier ends on a flat a mile from tidewater. These maps, however, are reconnaissance maps, and probably the position of the front of the glacier was

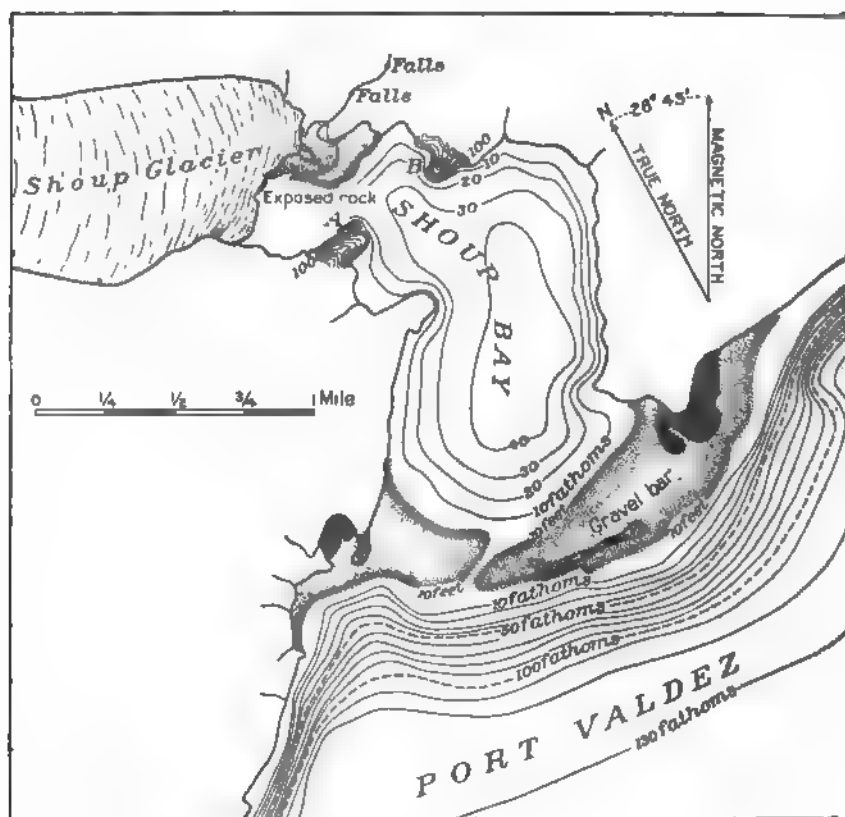


FIGURE 2. Map of Shoup Bay and Shoup Glacier, Port Valdez, July 18, 1909. Data south of point marked A from Coast and Geodetic Survey chart No. 8521; base line A-B assumed 0.34 mile; contour interval on land, 20 feet; submarine contour interval, 10 fathoms. Occupied points indicated by circles, intersected points by crosses.

not carefully located in the field. The growth of vegetation about the head of Shoup Bay shows that the glacier has not advanced more than a few rods beyond its present position for the last 15 years and very likely not for 50 years. The Coast Survey charts 8521 and 8519 show a distance between points A and B (fig. 2)¹ and the front of the ice one-third greater than that shown on our map. This difference may be

¹ Point A is the top of a small, round glaciated rock knob about 60 feet above sea level, on the south point of the entrance to the inner port of Shoup Bay. Point B is the middle one of three rocky projections on the north point of the entrance to the inner part of Shoup Bay. It is about 30 feet above sea level.



A. NORTH PART OF FRONT OF SHOUP GLACIER.
From point A, figure 2. July 13, 1908. Photograph G 10.



B. SOUTH PART OF FRONT OF SHOUP GLACIER.
From Point A, figure 2. July 13, 1908. Photograph G 12.



due to inaccuracies in our sketch or to the fact that the detailed work of the Coast Survey was not carried clear to the front of the glacier; or it may possibly, but not probably, be due to the glacier front standing farther back in 1900 and 1901, the years in which the field work for the Coast Survey charts was probably done. However, two men who obtained ice from the glacier in those years state that the ice was then in advance of its present position and that the ledges (visible in 1905, 1908, and 1909, and shown on the left of Pl. V, *A*, and the right of Pl. V, *B*) near the center of the ice front were not then visible. An advance of 50 feet would cover these ledges. They are shown just emerging from the ice in a photograph (Sc 61) taken by F. C. Schrader in 1898.

Photographs taken from point A, figure 2, on each of our three visits, as well as those taken by Tarr and Martin in August, 1909, show practically no fluctuation in the position of the northern half of the front of the glacier and slight variations in the position of the southern half. In July, 1908, the ice near the southern edge of the front was a little (estimated from photographs at 100 feet) in advance of its position on the other dates, and in July, 1905, the same portion was a little farther back than on the other dates. In July, 1905, a small push moraine, rising 20 feet above high tide, stood at the front of the ice 100 yards north of the southern end of the front. At later dates this moraine was not present.

Vegetation extends within a few yards of the ice, hence there is only a very narrow bare zone bordering the ice, in places practically none. This vegetation is 5 to 15 feet high and is mainly alders, at least out as far as points A and B, and the glacier front is now close to its maximum extension in the last 15 and probably in the last 50 years. The shores of the bay lack the usual forest, and most of the trees present are less than 3 inches in diameter. Though the trees are not large, it seems very improbable that the glacier has extended to the entrance of Shoup Bay within the last 100 years. The mouth of the bay is nearly closed by a morainic deposit, behind which is a considerable depression and in front of which is a steep slope to the flat bottom of Port Valdez. (See fig. 2.) Shoup Bay is, therefore, a hanging valley on the side of Port Valdez, the floor of the bay being more than 500 feet above the bottom of the port. The general post-glacial submergence of this part of the Alaskan coast has embraced the drowning of the main glacial trough (Port Valdez) and the hanging valley (Shoup Bay) on its side. (See submarine contour lines on figs. 1 and 2.)

Photographs of Shoup Glacier.

Sc 33. Distant view of glacier, looking N. 40° W. 1898.

Sc 61. Front of glacier, looking N. 45° W. from point on south 300 feet above sea level. This point is probably about one-fourth mile southwest of point A in figure 2. 1898.

- Sc 197. Distant view of glacier, looking north-northwest. October 26, 1898.
- P 662. Detail of front of glacier from point near south end of front. July 4, 1905.
- P 663. From same point as No. P 662. Nos. P 662 and 663 form a panorama.
- P 664. From same point as No. P 662.
- P 665. North part of front of glacier, from point A, figure 2. July 4, 1905.
- P 666. Center of front of glacier, from point A.
- P 667. South part of front of glacier, from point A. Nos. P 665 to 667 form a panorama.
- P 705. South part of front of glacier. July 4, 1905.
- P 706. A nearer view of the same. July 4, 1905.
- P 707. A still nearer view of part of the same, showing push moraine. July 4, 1905.
- G 10. Here reproduced as Plate V, A. North part of front of glacier, from point A, figure 2. Point A is the top of a small round glaciated rock knob about 60 feet above sea level, on the south point of the entrance to the inner part of Shoup Bay. July 13, 1908.
- G 11. Center of front of glacier, from point A.
- G 12. Here reproduced as Plate V, B. South part of front of glacier, from point A. Nos. G 10 to 12 form a panorama.
- G 73. North part of front of glacier, from point B, figure 2. Point B is the middle one of the three rocky projections on the north point of the entrance to the inner part of Shoup Bay. The station was about 30 feet above sea level. June 16, 1909.
- G 74. South part of front of glacier, from point B. Nos. G 73 and 74 form a panorama.
- G 75. North part of front of glacier, from point A, figure 2. June 16, 1909.
- G 76. Center of front of glacier, from point A.
- G 77. South part of front of glacier, from point A. June 16, 1909. Nos. G 75 to 77 form a panorama. This point was occupied by Tarr and Martin in August, 1909.

COLUMBIA GLACIER.

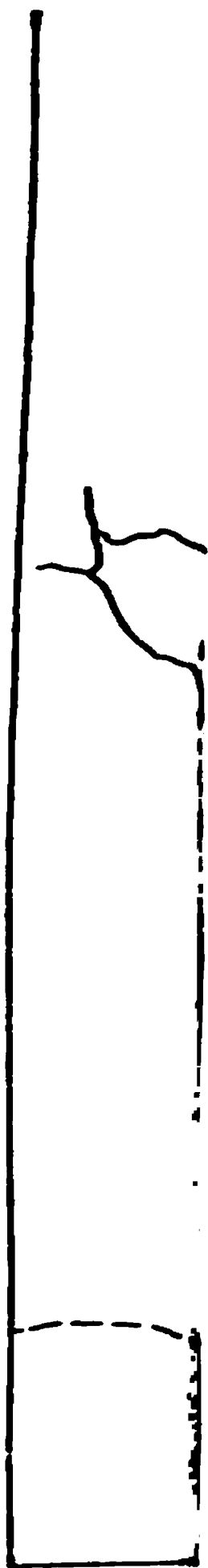
The Columbia Glacier is situated at the head of Columbia (or Glacier) Bay, 15 miles northeast of the town of Ellamar. Davidson indicates that this has also been called the Freemantle Glacier.¹ The name Columbia was applied by the Harriman Alaska Expedition (1899) and is now in common use. Gilbert² has described the Columbia Glacier in detail, and it is not necessary to duplicate his descriptions. Some additional information, mostly concerning the fluctuations of the glacier, will be given below. Other facts connected with this glacier have been noted by Tarr and Martin.³

We visited the Columbia Glacier on July 10, 1905, July 15, 1908, and June 24, 1909. On the two earlier dates a few notes and photographs were taken, and on the last date the bay and the front of the glacier were mapped and a series of photographs was obtained. Our chief observations have to do with the fluctuations of the glacial front that have taken place since the study of the glacier by Gilbert in 1899. Data concerning the position of the front of the ice are given on the accompanying map (Pl. VI), on which is also indicated approximately the position of the glacial front in 1899 as

¹ Davidson, George, The glaciers of Alaska that are shown on Russian charts or mentioned in older narratives: Trans. and Proc. Geog. Soc. Pacific, 2d ser., vol. 3, 1904, p. 33.

² Gilbert, G. K., Glaciers and glaciation: Alaska, vol. 3, Harriman Alaska Expedition, 1904, pp. 71-82.

³ Tarr, R. S., and Martin, Lawrence, The National Geographic Society's Alaskan Expedition of 1909: Nat. Geog. Mag., vol. 21, 1910, pp. 1-54.



June



A. JUNE 27, 1899

Photographed by Gilbert. Photograph Gt 355.



B. JUNE 24, 1909.

Photograph G 91.

WEST PART OF FRONT OF COLUMBIA GLACIER.

From point G, Pl. VI.



A. JUNE 26, 1899.

The ice front rests at the north (left) edge of the pond. Photograph G1 354.



B. JULY 10, 1905

Photograph P 673.

EDGE OF COLUMBIA GLACIER.

Shows fluted moraine and forest overturned by ice.



A JULY 15, 1908.

Photograph G 17.



B JUNE 24, 1909

Photograph G 85

EDGE OF COLUMBIA GLACIER.
Same locality as that shown in Plate VIII.

determined by a comparison of maps and photographs. Evidence of the advance of the ice front in the last 10 years has been obtained (1) at its west edge, (2) at the point where the glacier rests on a small island near the north end of Heather Island, and (3) at the north-east edge.

Gilbert's description and photograph (Pl. VII, *A*) show at the western end of the glacial front a bare zone 200 to 300 feet in width between the forest and the ice. This locality was not examined by us in 1905 and 1908. In 1909, however, the glacier had advanced sufficiently to cover the entire bare zone and to encroach upon the forest itself (Pl. VII, *B*). The forest was then being attacked by the ice, and considerable havoc among the trees had been caused by streams along the side of the glacier and by waves produced by the fall of icebergs. We estimated that the ice at its western edge was (in 1909) 500 feet in advance of its position in 1899, and that this advance had taken place in the main since July, 1908.

On the island on which the glacier rests north of Heather Island is a locality (point D, Pl. VI) from which we have photographs taken on June 26, 1899, July 10, 1905, July 15, 1908, and June 24, 1909. These photographs show the relations of the ice front to the forest and are reproduced as Plates VIII, *A* and *B*, and IX, *A* and *B*, respectively. The earliest of these photographs (Pl. VIII, *A*) shows the front of the ice resting at the north edge of a small pond. Directly back of the man in the picture are some barkless trees, which were probably killed by an advance of the ice some years previous to the advance that threw up the push moraine on which are the tilted living trees. The small push moraine on which the man stands marks a still more recent position of the ice front, but probably not more than three years later than the larger moraine. Back and to the left or north of this small moraine is exposed the fluted moraine described by Gilbert, which he thought had been exposed not more than one or two years.¹ The ice front in 1905 was 160 feet north of its position in 1899, at the edge of the small pond, and is not shown in the photograph taken in 1905 (Pl. VIII, *B*), but the tongue of ice in the background is farther advanced than it was in 1899. In 1905 grasses and weeds had begun to get a foothold on the fluted moraine surface. In 1908 the ice front north of the small pond was 60 feet north of its 1899 position, and the ice tongue in the background was less advanced than in 1905 and more advanced than in 1899 (Pl. IX, *A*). On June 24, 1909, the ice had advanced so as to cover the position of the small pond and had again invaded the forest (Pl. IX, *B*). From the photographs it is estimated that the ice front at this place was then 250 feet farther south than in 1899, and that the ice in the background was also farther advanced

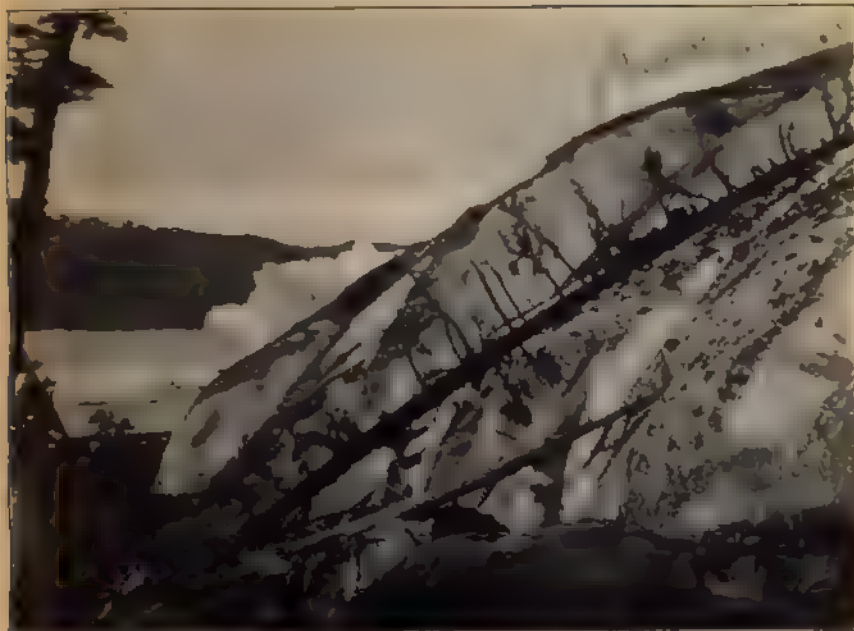
¹ *Op. cit.*, pp. 77-78.

than at the other dates noted. Tarr and Martin visited the Columbia Glacier on August 23, 1909, and reported that the position from which the above photographs were taken was then covered by ice. A photograph taken by them at that time from a position a few rods south of where the others were taken shows the ice 70 feet (estimated) farther advanced than on June 24, 1909, indicating an average rate of advance of 1.17 feet a day for the ice front. The actual rate of movement of the ice was doubtless considerably greater than this, for melting was at its maximum during this period.

Taking as the starting point the position of the front of the ice when it formed the push moraine on which are the tilted but still living trees (Pl. VIII, A), and estimating the date of this position as 1894, we have the following history of the fluctuations of the ice front: 1. Retreat (amount uncertain) and readvance (amount uncertain) to form the small push moraine on which the man is shown standing in Plate VIII, A. It is estimated that the readvance took place in 1897 and reached a point about 140 feet behind the first position. 2. Retreat of 60 feet, 1899. 3. Retreat of 160 feet, 1905. 4. Advance of 100 feet, 1908. 5. Advance of 310 feet, June 24, 1909. 6. Advance of 70 feet, reaching a point 120 feet in advance of the former (1894) maximum, August 23, 1909. There may have been other smaller fluctuations of which there is no record.

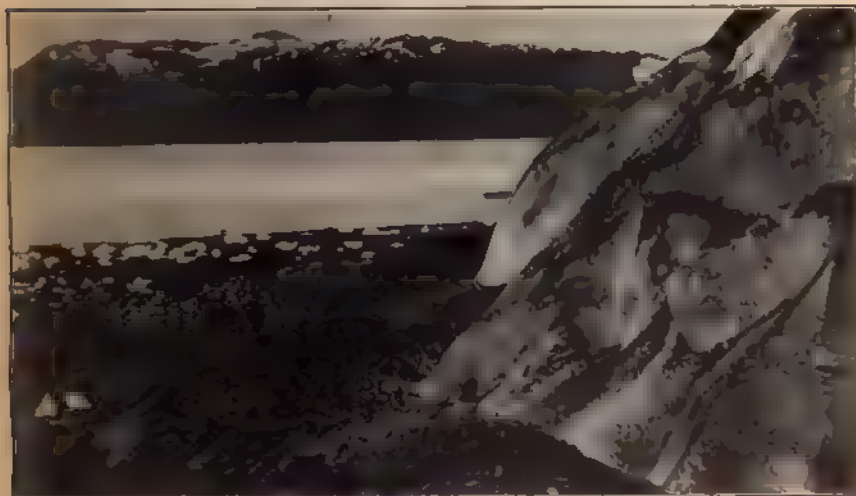
In the locality where these measurements were made the drift contains abundant fragments of trees as far north as the maximum retreat (1905). The forest, therefore, has probably extended considerably farther north than at present and has been overrun for an unknown distance by the ice advance in comparatively recent years—that is, prior to 1894.

The photographs (Pls. VIII and IX) are of interest also in showing the growth of vegetation on a freshly exposed till surface. In the first year or two no vegetation had gained a foothold; in the next six years very little grass had appeared, although fireweed (*Epilobium*), which is one of the first plants to cover ground recently vacated by ice, was very conspicuous in the outer part of the bared zone. In 1909 the ground was well covered by grass, but no trees nor shrubs were noticed. A number of the tilted trees that were alive in 1899 had died by 1905 and still others by 1909. The dropping of twigs and bark from the dead trees and the general decay of the trunks progressed comparatively little from 1899 to 1909. The impression one is apt to gain from visiting an area of forest invaded by ice or of ground recently bared by ice is that the time since the ice advanced or retreated is very much shorter than is really the case. Were it not for the evidence of dated photographs, an examination of this locality in 1909 would probably convince one



1. COLUMBIA GLACIER INVADING FOREST

West shore of island on which the glacier rests. June 24, 1909. Photograph G 87



2. PUSH MORaine AT FRONT OF COLUMBIA GLACIER

West shore of island on which the glacier rests. June 24, 1909. Photograph G 83

that the former maximum advance of the ice was three or four years rather than 15 or more years ago.

In the advance of the ice in 1909 into the previously disturbed forest some trees were pushed forward bodily without being overturned, although the inclination of some was changed. One tree had been moved ahead of the ice 100 feet by June 24, 1909, and even farther by August 23 of the same year, but was still nearly upright. This is the tall, limbless, barkless, nearly upright tree near the right of Plate IX, *B*. The same tree in a different position can be recognized in the other photographs of this locality (Pls. VIII, *A* and *B*, and IX, *A*). Such movement without overthrow of trees could be readily accomplished, when the ground was frozen, by the glacier pushing forward the frozen layer of soil, but in the case just described part of the movement took place in July and August, when the ground was not frozen.

On the western edge of the island on which the glacier rests the ice was also advancing on June 24, 1909. At the highest tide line the front of the ice had then just reached the limit of its farthest previous advance since the advent of the present forest and was again attacking the trees that had been killed or disturbed in that advance, estimated to have taken place in 1894. (See Pl. X, *A*.) The lowest tree resting on the ice shown in this illustration is visible at the extreme left of a photograph (G 19) taken on July 15, 1908, when the ice was 200 feet (estimated) north of this tree. On the beach at this place in 1909 a push moraine 25 feet high (Pl. X, *B*), composed of beach materials, bordered the ice and was in places actually being advanced by it. As this push moraine rested on land covered by the highest tides, it had probably been formed only a few weeks.

An ascent of the glacier was made near the western side of this island in June, 1909, and barometer readings checked on sea level showed that the height of the tidal ice cliff west of the island was at least 400 feet. In 1899 it was estimated to be 300 feet.

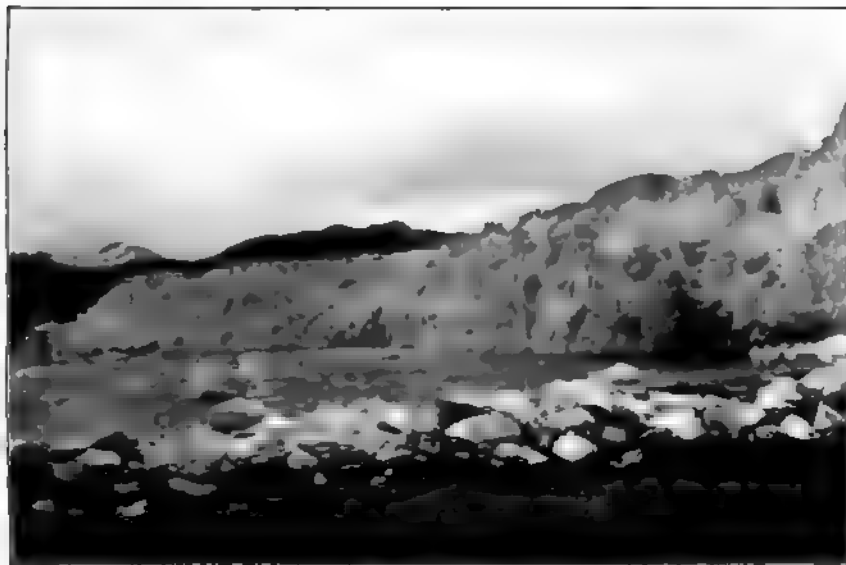
The eastern part of the island consists of a terminal moraine, which is not covered with bushes or trees and is of recent construction, probably dating from 1894. This moraine was being added to at the times of our visits in 1908 and 1909. In the earlier year examples of both push and terminal moraines were seen in process of formation. The former were in places being added to directly by deposits from the melting of the ice that was constructing them, and the latter showed, on a small scale, fine examples of knob and kettle topography in the making. In 1909 flows of mud were coming down from the melting edge of the ice and were reaching tidewater, where they aided in silting the tide flats just west of the north end of Heather Island.

In the moraine here described were many fragments of shells of pelecypods and gastropods, apparently of recent species. It is improbable that these forms live in the cold milky waters adjacent to the melting ice, and the presence of their remains in the recently deposited drift would indicate that the ice front was in geologically recent time considerably farther north than at present. The head of the north end of the eastern part of Columbia Bay is shallow, and it is suggested that a retreat of the ice front of not more than a mile might have exposed ground above tidewater, so that the drainage from the eastern part of the glacier would be diverted westward, leaving the eastern part of Columbia Bay free or nearly free of glacial waters, thus establishing conditions favorable to molluscan life at this point.

The wide tongue of ice that rests on the small island near the north end of Heather Island was pushing forward rapidly in June, 1909, and Tarr and Martin report farther advances in August of the same year. We have not sufficient information to determine definitely how far this tongue has advanced in recent years, but Gilbert's map ¹ and our impressions gained by a hurried visit in 1908 would indicate that the extreme southern part of this ice tongue in 1909 was 700 feet in advance of its position 10 years before. The reason for the extreme advance at this point is probably to be found not so much in the fact that this portion of the glacier is moving more rapidly than the rest of the ice stream as in the fact that the front, both east and west of this tongue, is attacked by warm ocean water and waves, which cause breaking down of the ice front as well as more rapid melting than on the land. The part of the glacier west of this island, where the water is probably deep, doubtless has a considerably higher rate of movement than the part east of the island where the water is very shallow. The projection of the tongue of ice above mentioned beyond the general front of the glacier was very noticeable in 1909 and is shown by photographs taken 10 years earlier, though it does not appear so prominently on the map made in 1899. The approximate location of the front of this tongue in both these years is shown on the map forming Plate VI.

At the northeastern corner of Columbia Bay (northeast of point C, shown in Pl. VI) there was in 1909 a well-defined bare zone 50 to 200 feet wide between the ice front and the forest which had been attacked by an earlier advance of the glacier. (See Pl. XI, *B*.) The ice was advancing on this bare zone in 1909. It was probably at this point that Gilbert estimated, from spruce trees which had grown since the forest was destroyed, that this catastrophe occurred not later than 1892. South of point C there is a small stretch of beau-

¹ Alaska, vol. 3, Harriman Alaska Expedition, Pl. XI.



A WEST PART OF FRONT OF COLUMBIA GLACIER

From point E, Plate VI June 24, 1909 Photograph G 88.



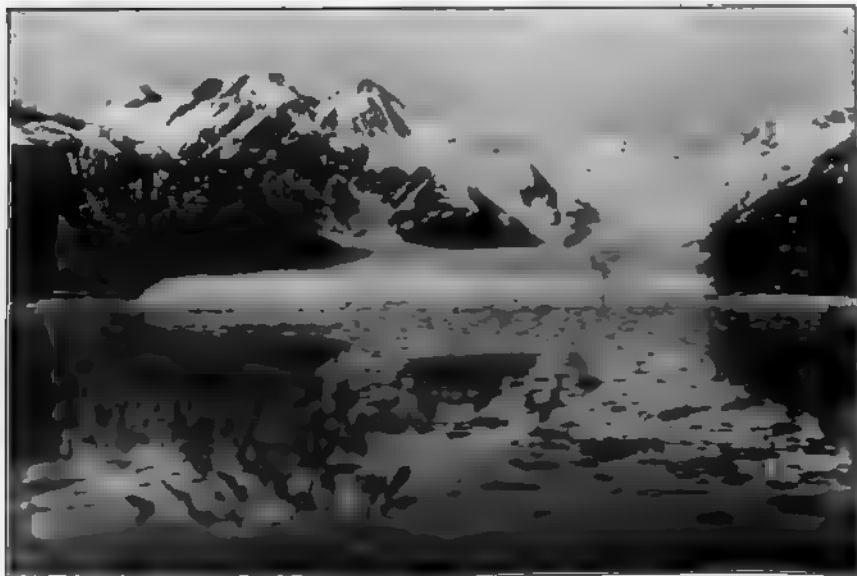
B EAST PART OF FRONT OF COLUMBIA GLACIER, BARE ZONE AND OVERTURNED FOREST.

From point C, Plate VI June 24, 1909 Photograph G 83.



A. EAST PART OF FRONT OF COLUMBIA GLACIER, TERMINAL MORaine, AND REMNANT OF FOREST.

From point B, Plate VI. June 24, 1909. Photograph G 82.



B. MEARES GLACIER, UNAKWIK BAY.

From point C, figure 3. June 26, 1909. Photograph G 96.

tiful and typically morainic country (Pl. XII, A), which is now well grassed over and which carries small scattered spruces and some thin tundra soil. These spruces range in size up to 6 inches in diameter, the largest being perhaps 15 or 20 years of age. South and southeast of this morainic area are remnants of a forest, which was partly destroyed by the ice when the outer portion of this moraine was formed (Pl. XII, A), that is, at the earliest advance recorded since the advent of the present forest—probably 50 years ago and possibly longer.

Photographs of Columbia Glacier.

Gi 337. Distant view of glacier from point near east side of entrance to Columbia Bay. June 25, 1899.

Gi 338. Western part of glacier from point near center of entrance to Columbia Bay. June 25, 1899.

Gi 339. Center of glacier. June 25, 1899.

Gi 340-344. Panorama of glacier from hill east of glacier. June 26, 1899.

Gi 345. Front of glacier from the east. June 26, 1899.

Gi 346. Surface of glacier. June 26, 1899.

Gi 346a. Surface of glacier. June 26, 1899.

Gi 347. Surface of broad moraine on glacier. June 26, 1899.

Gi 348 and 349. Forest overturned by recent advance of glacier. June 26, 1899.

Gi 350 and 351. Southeast front of glacier. June 26, 1899.

Gi 352 and 353. Fluted moraine at front of glacier from a position probably a few yards northwest of point D, Plate VI. June 26, 1899.

Gi 354. Here reproduced as Plate VIII, A. Fluted moraine, forest overturned by ice, and edge of glacier, from point D, Plate VI. See under P 673. June 26, 1899.

Gi 355. Here reproduced as Plate VII, A. West end of front of glacier from point G, Plate VI. See under G 90. June 27, 1899.

Gi 356. Push moraine on western shore of Columbia Bay. June 27, 1899.

Gi 357 and 358. Panorama of western part of front of glacier from western shore of Columbia Bay. June 27, 1899.

Gi 359. Front of glacier from western shore of Columbia Bay. June 27, 1899.

Gi 360. Front of glacier from hill on western shore of Columbia Bay. June 27, 1899.

P 671 and 672. Front of glacier, from position near point E, Plate VI. July 10, 1905.

P 673 and 674. No. 673 is here reproduced as Plate VIII, B. Panorama of fluted moraine, forest overturned by ice, and front of glacier from point D, Plate VI. Point D is on the northern part of the small island on which the front of the glacier rests. This position was overridden by the ice in August, 1909. July 10, 1905. From the same position photographs have been taken as follows: Gi 354, June 26, 1899; G 17 and 18, July 15, 1908; G 85 and 86, June 24, 1909.

G 15. Front of glacier from position one-half mile northeast of point D, Plate VI. July 15, 1908.

G 16. Ice overriding moraine from position about one-fourth mile northeast of point D, Plate VI. July 15, 1908.

G 17 and 18. No. 17 is here reproduced as Plate IX, A. Panorama of fluted moraine, forest overturned by ice, and front of glacier from point D, Plate VI. See under P 673. July 15, 1908.

G 19. Front of glacier and push moraine from a position a few rods west of point D, Plate VI. July 15, 1908.

G 20 and 21. Morainic topography in process of formation from position about one-fourth mile northeast of point D, Plate VI. July 15, 1908.

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G 80 and 81. Panorama of front of glacier from point A, Plate VI. Point A is a rocky point on the east shore of Columbia Bay $1\frac{1}{2}$ miles north of Emerald Cove. June 24, 1909.

G 82. Here reproduced as Plate XII, A. Front of glacier and old moraine from point B, Plate VI. Point B is on the summit of a beautifully developed moraine at the north edge of the undisturbed forest west of the mouth of the stream which enters Columbia Bay at its northeast corner. June 24, 1909.

G 83. Here reproduced as Plate XI, B. Front of glacier and overturned forest, from point C, Plate VI. Point C is close to the edge of the ice and 0.3 mile north of point B. June 24, 1909.

G 84. Front of glacier and mud flows from position about one-half mile east of point D, Plate VI. June 24, 1909.

G 85 and 86. No. 85 is here reproduced as Plate IX, B. Forest overturned by ice and edge of glacier, from point D, Plate VI. June 24, 1909. See under P 673.

G 87. Here reproduced as Plate X, A. Front of glacier from position a few rods west of point D, Plate VI. June 24, 1909. The lowest (dead) tree in this photograph is seen at the extreme left of G 19.

G 88. Here reproduced as Plate XI, A. Front of glacier from point E, Plate VI. Point E is the top of a ledge of coarse-grained graywacke on the beach on the west side of the island on which the glacier rests. This ledge is not entirely covered by ordinary high tide. June 24, 1909. Photograph G 184 was taken from this same point.

G 89. Front of glacier, looking N. 51° W. (magnetic) from point F, Plate VI. Point F is a prominent exposure of massive graywacke on the end of a point projecting from the west side of Heather Island, about a mile from the south end of this island. June 24, 1909.

G 90 and 91. Here reproduced as Plate VII, B. West part of front of glacier from point G. Point G is on the end of a rocky point on the west side of Columbia Bay. The actual position from which the photograph was taken is covered at high tide. June 24, 1909. Photograph Gi 355 was taken from this same position on June 27, 1899.

G 92. Front of glacier from point near north shore of Glacier Island. June 25, 1909.

G 174. Front of glacier from position 1,000 feet south of point C, Plate VI. June 24, 1909.

G 175. Front of glacier from station on moraine about three-fourths of a mile southwest of point B. June 24, 1909.

G 176. Front of glacier from station about one-fourth of a mile east of Point D. June 24, 1909.

G 177. Surface of glacier from station on glacier about one-eighth of a mile north of point D. June 24, 1909.

G 178. Front of glacier from same station as G 177. June 24, 1909.

G 179. Crevasse in glacier from same station as G 177. June 24, 1909.

G 180. Surface of glacier from same station as G 177. June 24, 1909.

G 181. Front of glacier and push moraine from a position a few rods west of point D. June 24, 1909.

G 182. Front of glacier and overturned forest from a position a few rods west of point D. June 24, 1909.

G 183. Here reproduced as Plate X, B. Front of glacier and push moraine from a position a few rods west of point D. June 24, 1909.

G 184. Front of glacier from point E. See under G 88. June 24, 1909.

G 185. Front of glacier from a position about one-eighth of a mile southeast of point E, Plate VI. June 24, 1909.

G 186 to 189. Icebergs from glacier. June 24, 1909.

G 191. Front of glacier from near north shore of Glacier Island. June 25, 1909.

UNAKWIK INLET.

GENERAL FEATURES.

Unakwik Inlet is 16 miles west of Glacier Bay and extends northward from the main body of Prince William Sound for 22 miles (estimated). The bay is from 1 to 3 miles wide and does not appear to be very deep; at any rate there are shallows in places due to morainic accumulations. One of the most noticeable of these is in the vicinity of Jonah Bay. The northern part of Unakwik Inlet is, however, fiord-like and is probably deep. On the west side, about Jonah Bay, are a few small glaciers high up in the mountains. Three of these are on the flanks of the most prominent mountain on the west side of Unakwik Bay. We named this Unakwik Peak. From its western side descend the Amherst and Crescent glaciers of Port Wells. East of Unakwik Inlet the Pedro Glacier lies back in the mountains, and its waters reach tidewater through Miners Lake and Miners River. Four miles north of the mouth of this river is a small, narrow, beautiful, cascading ice stream, named Brilliant Glacier. Ranney Glacier is a prominent feature of the upper part of Unakwik Inlet. This glacier does not reach tidewater, but a stream (Ranney Creek) from the glacier enters the northwest side of the bay half a mile west of the front of Unakwik Glacier.

MEARES GLACIER.

The Meares Glacier is situated at the head of Unakwik Inlet. We have named it after one of the early (1786) explorers of Prince William Sound, Capt. John Meares. Little definite information concerning this glacier is available aside from the sketch and photographs here noted. Fidalgo (1790) and probably also Vancouver (1794) visited this bay, found the upper part blocked by ice, and noted the noise made by the fall of ice from the glacier front. The maps of that time are too inaccurate to give definite information concerning the position of the front of the glacier. On August 25, 1905, we made a hurried visit to the head of Unakwik Inlet, but made no map of the glacial front and took no photographs because our supply of films was exhausted. On June 26, 1909, we again visited the bay and mapped (fig. 3) and photographed (Pl. XII, *B*) the front of the glacier.

The Meares Glacier, although not so large as others, is one of the most beautiful ice streams of Prince William Sound. The end of the glacier is about 0.8 of a mile wide and forms a vertical wall of pure ice which we estimated to be 300 feet high. It is actively discharging. The glacier is formed by two ice streams, which descend from lofty mountains. The northern stream is the larger, and from the junction of the two a small medial moraine extends westward to the end of the glacier, keeping well toward its southern side.

In 1905, as viewed from the distance of a mile, the bushes and trees seemed to be close to the ice, and no bare zone (or at most a very narrow one) was visible between the ice and the forest. In 1909 the

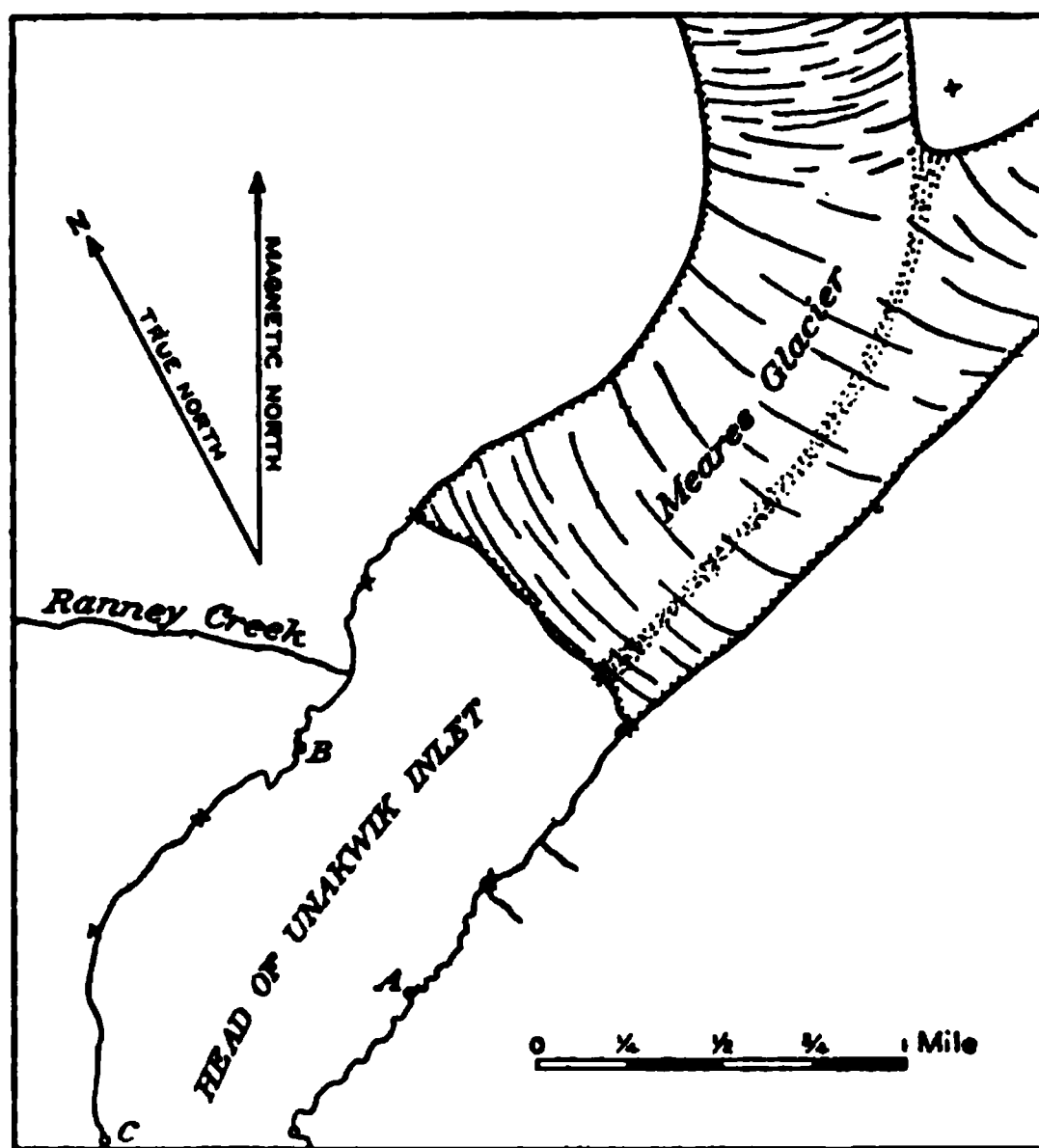


FIGURE 3.—Map of Meares Glacier and head of Unakwik Inlet June 26, 1909. Scale is approximate. Occupied points indicated by circles, intersected points by crosses.

front of the glacier appeared to be a little in advance of its position of four years before. On the south side of the glacier near the front was a brown zone, estimated to be 200 feet wide, which appeared to be dead vegetation rather than bare rock, and on the northern edge of this brown zone, at the southern edge of the glacier, were a few small trees. There is a sparse forest close to the glacier containing trees 10 inches (estimated) in diameter.

The ice is now, therefore, at its maximum advance within the last 100 years and quite probably at the maximum within two or three times that period.

Photographs of Unakwik Inlet and Meares Glacier.

G 93. Brilliant Glacier, east side of Unakwik Inlet. June 26, 1909.

G 94. North part of front of Meares Glacier from point A, figure 3. Point A is on a small flat-topped rock point, the first of the two most prominent points on the south shore between the bend near the head of Unakwik Inlet and the glacier. It is about half a mile from the point at the bend of the inlet. June 26, 1909.

G 95. South part of front of Meares Glacier from point B, figure 3. Point B is on a small rocky projection on the north shore of the head of Unakwik Inlet, situated about 300 yards west of the gravel fan at the mouth of Ranney Creek. The small point next west of B is covered with alders. June 26, 1909.

G 96. Here reproduced as Plate XII, B. Meares Glacier from point C, figure 3. Point C is a small rocky point directly opposite the prominent point on the east side of Unakwik Inlet at the bend near its head. Just back (west) of point C rises a very steep mountain side. June 26, 1909.

PORT WELLS.

GENERAL FEATURES.

Port Wells, with its two large arms, College and Harriman fiords, forms the extreme northwestern part of Prince William Sound. The valley in which Port Wells lies is very extensive, reaching from

the front of the Harvard Glacier south-southwest through Cochrane Bay to the head of Port Nellie Juan, a distance of 56 miles at sea level. The same straight depression is continued for an unknown distance both north-northeast and south-southwest of the points named. (See Pl. I, in pocket.)

The glaciers of Port Wells were seen in part by Mendenhall in 1898 and were studied by the Harriman Alaska Expedition in 1899. We made a hurried visit to Port Wells in August, 1905, and took a few notes and photographs. On August 11, 1908, we visited the Barry Glacier. From June 28 to July 2, 1909, we were in Port Wells and at this time mapped the port and its glaciers (Pls. I and XVII and fig. 4) and obtained a few photographs. Port Wells and its glaciers form a very inviting field and would well repay careful study.

West of Port Wells are extensive unexplored ice fields, from which numerous glaciers emerge. Many of these glaciers reach sea level. There are also numerous smaller ice streams, each of which comes from a névé area of its own, so that the glacier and the névé are practically one. The southernmost ice field of Port Wells is that about the head of Harriman Fiord, which feeds the northeastward-moving Harriman Glacier. The same ice field apparently furnishes material to the Bettles Glacier, flowing to the east, and to the Pigot and Billings glaciers, which flow southward. It is probable that ice from the same field moves westward into the drainage basin of Turnagain Arm of Cook Inlet.

COLLEGE FIORD.

GENERAL FEATURES.

The glaciers of College Fiord (fig. 4) have been described by Gilbert.¹ Additional data, most of them concerning the largest three glaciers, the Yale, the Harvard, and the Bryn Mawr, are here given.

Along the west side of College Fiord is a lofty mountain range; the prominent peak at the south end of this range is named Mount Emerson, after Prof. B. K. Emerson, who was a member of the Harriman Alaska Expedition of 1899. Within a short distance north of this peak the mountain range carries several glaciers that hang high above the fiord, and beyond these are others which descend to sea level and have been named, from south to north, the Wellesley, Vassar, Bryn Mawr, and Smith glaciers. North of the latter group is the Baltimore Glacier, which does not reach sea level (Pl. XIV, A).

YALE GLACIER.

The first description of the Yale Glacier was written by Mendenhall² in 1898. In 1899 the glacier was visited by the Harriman

¹ Gilbert, G. K., *Alaska*, vol. 3, Harriman Alaska Expedition, 1904, pp. 81-89, 175-176.

² Mendenhall, W. C., *A reconnaissance from Resurrection Bay to the Tanana River, Alaska*, in 1899, *Twentieth Ann. Rept. U. S. Geol. Survey*, pt. 7, 1900, pp. 273, 325.

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Alaska Expedition and described by Gilbert.¹ In 1905 the senior author of this report made a hasty visit to the east arm of College Fiord and noted that the only evidence of either recent retreat or advance of the ice front was a very narrow bare zone on the east side of the glacier front.

Notes and photographs by both Mendenhall and Gilbert, compared with observations made in 1909, show that there has been no marked

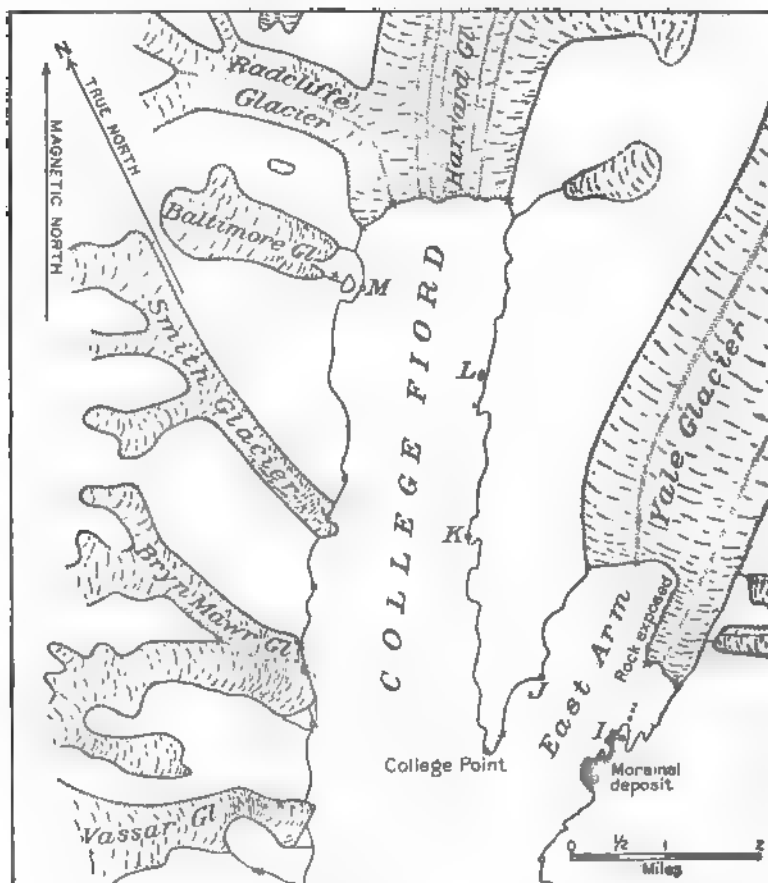


FIGURE 4.—Map of northern part of College Fiord, Port Wells, June 30, 1909. Occupied points indicated by circles, intersected points by crosses.

advance at the edges of the ice front since 1898, but that the eastern side of the glacier has advanced slightly. Gilbert says:

The trough in which it [the glacier] lies is forested along the water edge on both sides for the greater part of the distance from the main fiord to the glacier, but barren in the immediate vicinity of the glacier. There are straggling trees high on the valley wall at the end of the glacier, but they do not come down close to the ice.

¹ Harriman Alaska Expedition, vol. 3, 1904, p. 83.



A. EAST PART OF FRONT OF YALE GLACIER.

From point 1, figure 4. July 1, 1909. Photograph G 202.



B. CENTER AND WEST PART OF FRONT OF YALE GLACIER.

From point 1, figure 4. July 1, 1909. Photograph G 203.

This was the condition of the surroundings at the time of our visit in 1909, except that there was a very narrow bare zone on each side of the glacier. On the east side the ice was separated from grass and alders by only a few rods of rock débris. Possibly these narrow bare areas are due to no more than the rapid melting away of the ice in the summer. Although the sides of the fiord are barren of trees, they are clothed with a tangle of salmonberry bushes and alders up to the line where the scattered timber begins. This line is very distinct on each side of the fiord (Pl. XIII, A, right side). It is practically horizontal at an elevation of 900 feet (estimated) and probably marks the lateral margin of the great ice stream which once occupied the entire fiord.

The published maps show the front of the glacier as approximately straight, but intersections on the front in 1909 showed that the east part of the glacier projects beyond the west part. The former portion is held in place by a hard ledge of rock extending about parallel with the axis of the glacier. Plate XIII, B, shows this feature of the front as well as portions of the rock projecting from under the ice cliff. This ledge shows distinctly in a photograph made by Curtis in 1899. The tiny islands in the foreground of Plate XIII, B, are gull rookeries and belong to the same hard rock layers. The station from which this view was taken is on a glaciated knob of the same resistant formation. Careful examination of the Harriman expedition photograph shows that the ice front was then probably much as it is now. The irregular shape may have been overlooked in a rather cursory survey, for we have noticed that in a perspective view ice fronts are very deceptive and that a seemingly straight wall of ice shows marked irregularities when more closely examined.

The west side of the glacier is probably resting on a surface above high tide, as noted by Gilbert. In fact, at two places small portions of such a surface may be seen, though an advance of a few yards would cover them. On the extreme west a small morainal deposit is being made.

The presence of a mature alder thicket close to the ice front indicates that the glacier is now very near its maximum advance in a period of perhaps 50 or more years. The gravelly point a mile below the glacier on the east side of the fiord is probably the remains of an older terminal (recessional) moraine. This moraine, however, is later than the time of greater ice extension indicated by the lower limit of the spruce forest about 900 feet above sea level.

HARVARD GLACIER.

The Harvard Glacier is the trunk glacier of College Fiord and is the largest and most impressive of that inlet. The glacier has several feeders and six distinct medial moraines, as well as other less distinct

drift accumulations on its surface. The frontal cliff is estimated to be 350 feet high, and at the times of our visits was discharging abundantly, the water down as far as College Point carrying much ice. Waves generated by the fall of icebergs and the strong currents in front of the glacier make it impracticable to approach near the glacial front in a small boat. Reports are current that native seal hunters in bidarkas have been drawn under the glacier by northward flowing currents. At the time of our visit in 1909 there were marked northward-flowing currents on both sides of the fiord near its upper end.

The Harvard Glacier was visited by the Harriman Alaska Expedition in 1899.¹ We saw and photographed the glacier at a distance in 1905 and from a nearer point in 1909 (Pls. XIV, A and B, and XV, A).

Gilbert's description calls attention to the relation of the Harvard Glacier to its southernmost feeder on the west, the Radcliffe Glacier, and notes that the two barely coalesced in 1899, and that the medial moraine bounding the feeder extended without curvature to the frontal cliff. A photograph taken in 1905 shows that practically the same conditions prevailed at that date. In 1909, however, this medial moraine was distinctly curved (as Gilbert predicted it would be should the glaciers advance), and it followed the general axis of the trunk stream for half a mile before reaching tidewater. (Pls. XIV, A, and XV, A.) Thus the position of the west part of the front of the Harvard Glacier was approximately the same in 1899 and 1905, but there was an advance prior to July 1, 1909, at which time the ice front is estimated to have been half a mile farther south than on the earlier dates.

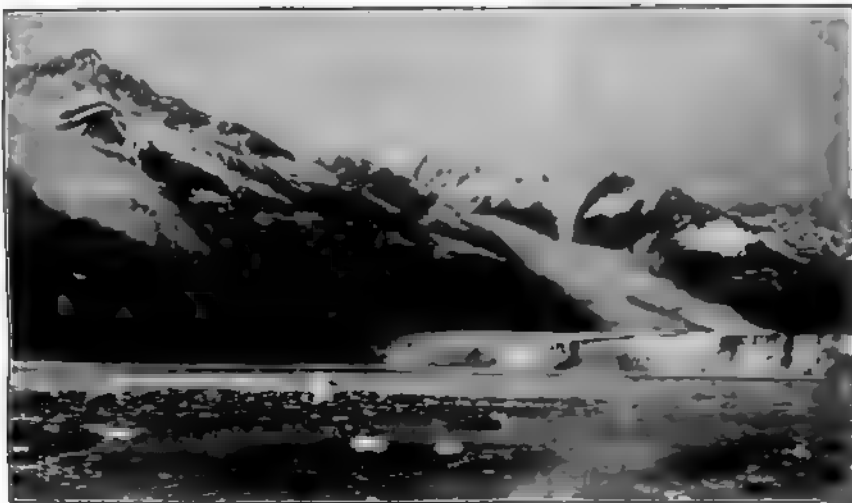
Gilbert reports, from a study of photographs, that in 1899 the eastern part of the front of the Harvard Glacier was 1,000 to 2,000 feet north of the apex of an alluvial fan made by a stream from a small hanging glacier. A photograph taken 10 years later (Pl. XIV, B), compared with his statements and photograph,² indicates that in 1909 the eastern part of the glacial front had advanced beyond its position in 1899 by a distance roughly estimated at a quarter of a mile.

SMITH GLACIER.

The Smith, which is the first tidewater glacier south of the Harvard, has not been studied in detail. This glacier is shown in photographs made in 1899 and 1909, but these were taken at some distance and were not intended primarily to show this glacier. A comparison of these photographs and of maps of College Fiord made in the above-mentioned years indicates that the front of the glacier, especially

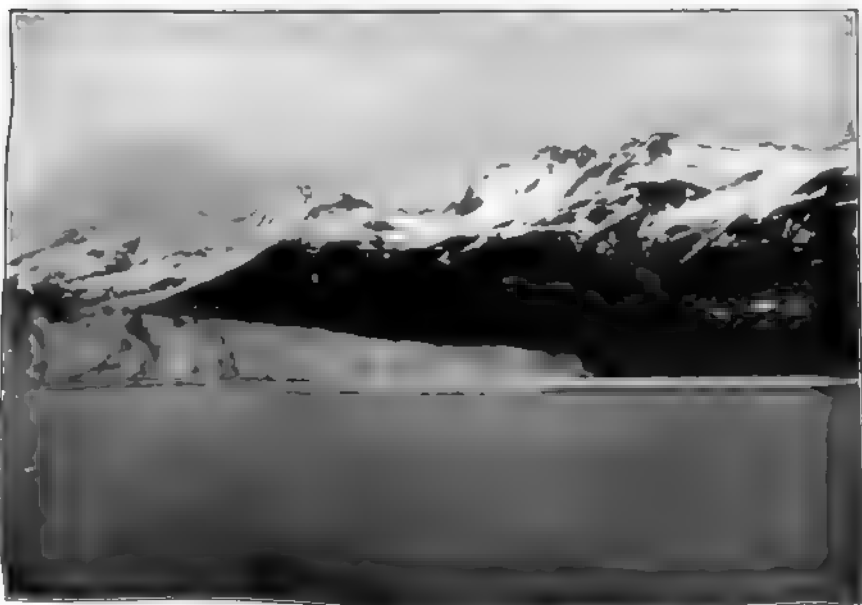
¹ Alaska, vol. 3, Harriman Alaska Expedition, 1904, pp. 84-86, 89.

² Idem, vol. 1, 1901, plate facing p. 72.



A. WEST PART OF FRONT OF HARVARD GLACIER,

From point L, figure 4. The glacier on the left, not reaching tidewater, is the Baltimore, and the large ice stream joining the Harvard Glacier is the Radcliffe. July 1, 1909. Photograph G 208.



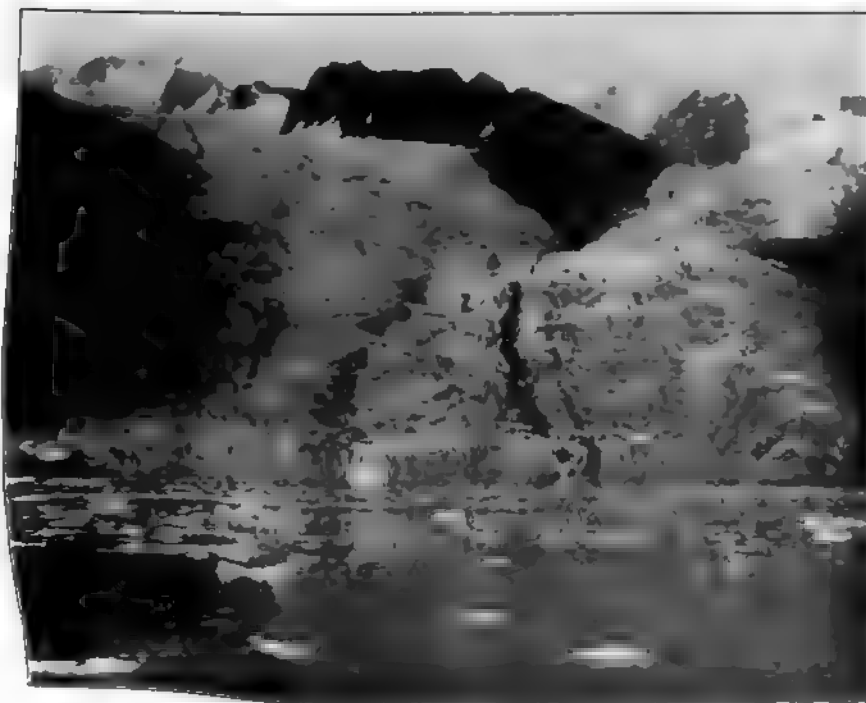
B. EAST PART OF FRONT OF HARVARD GLACIER

From point M, figure 4. July 1, 1909. Photograph G 109.



A. HARVARD GLACIER

From point K, figure 4. The glacier on the left is the Redcliffe. July 1, 1909. Photograph G 207



B. BRYN MAWR GLACIER

August 21, 1905. Photograph P 692.

the southern half of the front, was more advanced in 1909 than it was 10 years earlier. The amount of this advance can not be accurately estimated from the data at hand, but the part of the front projecting beyond the shore line (see fig. 4) probably was not present in 1899. This advance is perhaps as much as 600 feet, and judging from the advances recorded in the adjacent glaciers (Harvard and Bryn Mawr) it has probably taken place since 1905.

BRYN MAWR GLACIER.

The Bryn Mawr Glacier is the largest and the most attractive of those on the west side of College Fiord. It is a veritable ice cascade and gives a vivid impression of a rushing torrent to one who views the glacier from a point directly in front and not far distant. (Pl. XV, *B*.) The glacier is formed by two trunk streams, which unite about a mile back from tidewater. The two streams flow in a deep valley of fairly gentle slope, but just before joining they plunge over a steep slope. Below this junction the glacier has a gentle gradient for about half a mile; then it is brought by another and still more tumultuous fall nearly to tidewater, before reaching which it again receives a flattened profile on the floor of College Fiord. These ice cascades are shown in Plate XV, *B*, and Plate XVI, *B*, and the profile of the lower part of the glacier is shown in Plate XVI, *A*. Below the crest of the upper fall the glacier lies in a very shallow trough. The crests of these ice falls are thought to represent the approximate upper limits of the trunk glacier of College Fiord at two earlier stages in its history; the Bryn Mawr Glacier of to-day occupies a hanging valley on the side of this fiord. Similar characters are shown by other glaciers of College Fiord, and their significance has been noted by Gilbert.¹

A comparison of the photographs taken in 1899² with those taken in 1909 indicates that the glacier was farther advanced at the latter date, and that its front (especially the southern half of the front) deployed more widely on the shallow bottom of College Fiord. A photograph taken in 1905 (Pl. XV, *B*) and the impression gained from a brief study four years later indicate that the glacier was less advanced at the earlier date, when it was at approximately the same position as in 1899. The amount of the advance shown in the photographs taken in 1909 can not be estimated closely from the data at hand, but it is probably as much as 500 feet.

VASSAR GLACIER.

The front of the Vassar Glacier is about 200 feet high and is covered with débris to such an extent that the underlying ice is seen only by

¹ *Op. cit.*, vol. 1, pp. 86-88, 175-176.

² See *idem*, vol. 2, p. 276, and vol. 3, frontispiece.

close examination. The south part of the front of this glacier was in 1909 as far advanced as it had been in recent years, whereas the north part of the front has very recently been 200 feet farther east. We made no measurements or photographs of this glacier in 1905, but our impression is that in 1909 its front projected farther into College Fiord than it did four years before. Gannett's map of 1899 does not show this glacier projecting east of the coast line, as it did 10 years later (fig. 4). The 1899 map, however, is drawn on a very small scale, and is evidently a sketch map, so that this detail may have been omitted. Still it is very probable that the Vassar Glacier did advance between 1905 and 1909, as did the Bryn Mawr and Harvard glaciers and probably the Smith Glacier. The advance of the Vassar Glacier since 1899, and most probably since 1905, is thought to be about 500 feet.

WELLESLEY GLACIER.

The Wellesley Glacier carries considerable débris on its north side near its front. There is a bare morainic zone along both sides of the front of this glacier, and willows 10 feet high are scattered over this morainic area. Herbaceous vegetation comes practically to the edge of the ice. It is estimated that the ice front in 1909 stood as far forward as it had at any time in the last five years and that the morainic area carrying the willows represents an advance of 15 or more years ago. No further details concerning the Wellesley Glacier are available.

Photographs of glaciers of College Fiord.

P 692. Here reproduced as Plate XV, *B*. Bryn Mawr Glacier. August 21, 1905.

P 693. Harvard Glacier. August 21, 1905.

G 109. Here reproduced as Plate XIV, *B*. East part of front of Harvard Glacier, from point M, figure 4. July 1, 1909. Point M is on the eastern edge of the rocky point in front of the Baltimore Glacier and is about 40 feet above sea level.

G 110. West end of front of Harvard Glacier; Baltimore Glacier at left. July 1, 1909.

G 111. Side view of Bryn Mawr Glacier. July 1, 1909.

G 201. West side of College Fiord from bay northwest of Amherst Glacier. June 30, 1909.

G 202 and 203. Here reproduced as Plates XIII, *A* and *B*. Panorama of front of Yale Glacier from point I, figure 4. July 1, 1909. Point I is on a small round rock knob and 30 or 40 feet above sea level. This is one of a series of knobs formed by a hard rock layer whose northeastward prolongation is marked by small islands. A cairn 3 feet high in an open space marks point I.

G 204 and 205. Panorama of east part of front of Yale Glacier from point J, figure 4. July 1, 1909. Point J is on a smooth, rounded rock point, the most prominent one between College Point and the north end of the front of the Yale Glacier. The station is a few feet from the water's edge on a rock strongly marked by glacial grooving.

G 206. Here reproduced as Plate XVI, *B*. Bryn Mawr Glacier from end of College Point. July 1, 1909.

G 207. Here reproduced as Plate XV, *A*. Harvard Glacier from point K, figure 4. July 1, 1909. Point K is a rocky point on the east side of College Fiord, directly opposite the Smith Glacier.

G 208 and 209. No. 208 is here reproduced as Plate XIV, A. Panorama of Harvard Glacier from point L, figure 4. July 1, 1909. Point L is on a small rock island on the east side of College Fiord, about $3\frac{1}{2}$ miles south of the Harvard Glacier. The island is very bushy on the extreme top, and the station occupied is on the west side of the island at nearly as great an elevation.

G 210. Here reproduced as Plate XVI, A. West side of College Fiord from point L, figure 4. Smith Glacier on right. July 1, 1909.

G 211. Harvard Glacier from boat opposite Bryn Mawr Glacier. July 1, 1909.

G 212. Bryn Mawr Glacier. July 1, 1909.

HARRIMAN FIORD.

GENERAL FEATURES.

The first recorded visit to Harriman Fiord was made by the Harriman Alaska Expedition in 1899, and the main glaciers were named by the members of that expedition. Prior to that date the Barry Glacier, lying at the sharp bend in the fiord, was the only one that had been recorded, and earlier explorers evidently had assumed that this ice stream filled the whole end of this arm of Port Wells (Pl. XVII). That this glacier, however, has not extended across the fiord for a long series of years is shown by the vegetation, including a sparse forest that comes down nearly to the water's edge opposite the glacier and by well-authenticated reports that native seal hunters had repeatedly gone past the front of the Barry Glacier and into the inner part of the fiord. To the Harriman expedition is due the credit of bringing to public knowledge this magnificent fiord, hemmed in by lofty mountains whose sides and valleys carry many glaciers. Five of these ice streams reach tidewater.

Among the localities in Alaska that derive scenic interest from glaciers three stand out prominently—Glacier Bay, the Yakutat-Disenchantment Bay region, and Harriman Fiord. The panorama of mountain, ice, snow, and water that unfolds itself from points along the southeastern shore of Harriman Fiord has few equals anywhere else in the world.

The most striking peaks about the fiord are Mount Gilbert on the north and a four-peaked summit, Mount Muir, on the west of the Serpentine Glacier. (See Pl. XVIII.) Rough estimates of their altitudes made by vertical angles gave results approximating 10,000 feet for each. These peaks are named after Grove Karl Gilbert, a geologist on the United States Geological Survey, and John Muir, the veteran naturalist, who were both among the first scientists to see Harriman Fiord.

The records of the fluctuations of the glaciers along Harriman Fiord are unfortunately fragmentary. Gilbert's descriptions are derived mainly from a study of photographs and from accounts by others.¹

¹ Op. cit., vol. 3, pp. 89-97.

Our photographs taken in 1905 were few, and in 1908 time permitted only a hurried view of the Barry Glacier. In 1909 a little more time was spent in Harriman Fiord, but very much less than the locality deserves. Sufficient data are at hand, however, to show that the Barry and Surprise glaciers have retreated markedly in the past 10 years and that the Serpentine, Cataract, Harriman, and Toboggan glaciers have shown much less change in that time.

BARRY GLACIER.

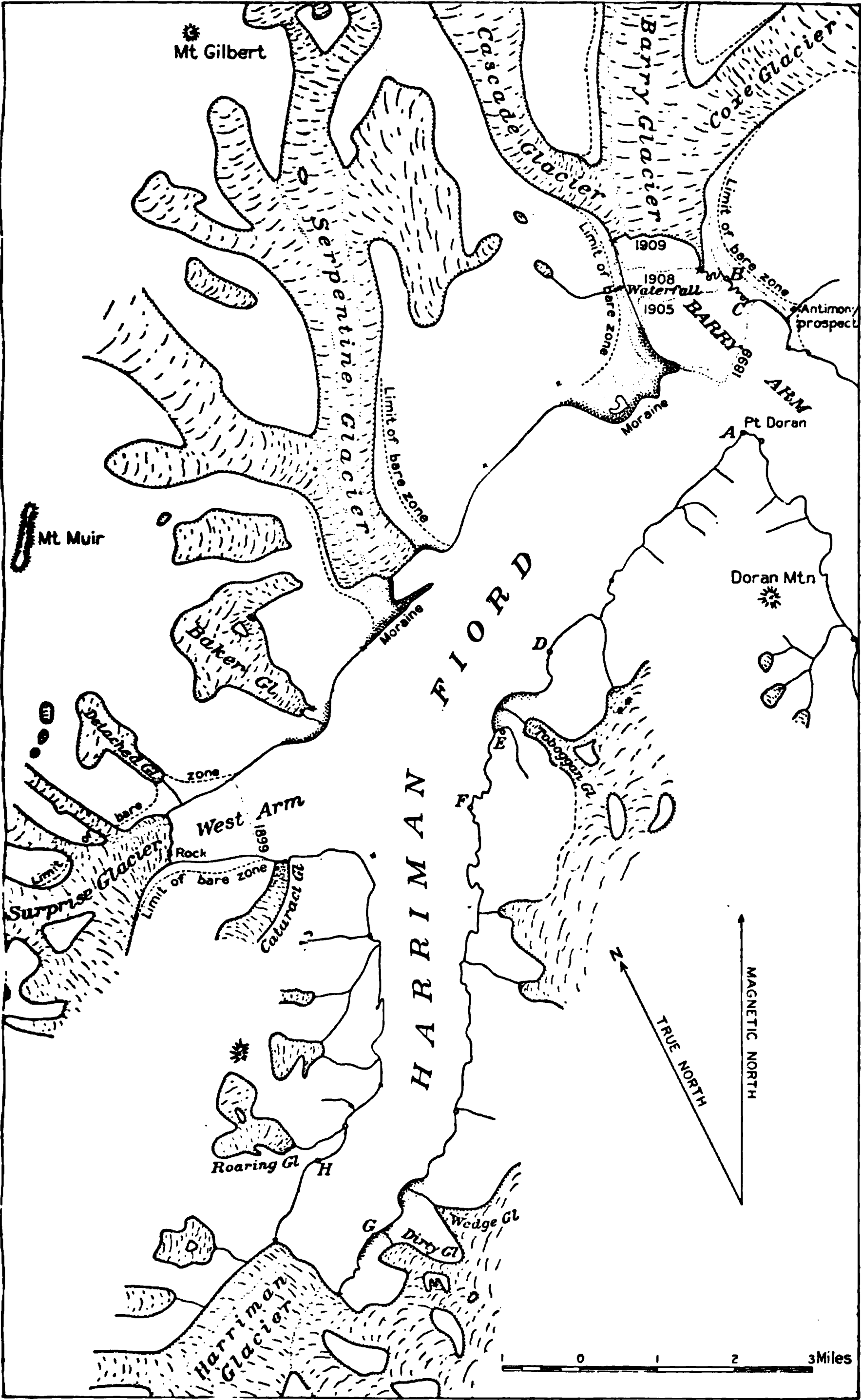
The Barry Glacier is in some ways the most interesting on Harriman Fiord, and the record of its fluctuations is more complete than that of any other on Port Wells. In 1899 the front of the glacier was well out into the waters of Harriman Fiord, and 10 years later this glacier showed a much greater retreat than any other that we have studied. This glacier has been called the Washington,¹ but the name Barry was proposed earlier and is now in common use.

From 1899 to 1909 the Barry Glacier retreated approximately 2.1 miles, measured along the axis of the glacier. (See Pl. XVII.) From 1899 to 1905 the retreat was 1.2 miles; from 1905 to 1908, 0.4 mile; and from August 11, 1908, to June 29, 1909, 0.5 mile. In 1899 a long point of ice extended forward from the eastern part of the glacial front; in 1905 there was a similar projection from the western part, and in 1909 a shorter point extended forward from the eastern part. The two earlier points of ice were probably in the main unmelted stagnant portions of the glacier resting mostly above tide level, but the 1909 projection was part of the moving glacier.

Along both sides of the Barry Glacier an extensive bare zone lies between the ice and a mature spruce forest (Pls. XIX and XX). Near the antimony prospect southeast of the glacier there are fragments of trees in the drift, and near the southern limit of the bare zone at this locality are a number of fallen trunks. The limit of this bare zone indicates the maximum advance of the ice since the growth of the present forest. The ice probably stood near this point of maximum advance for a considerable period, during which were deposited the morainic accumulations on the west side of the bay on which the glacier is situated. No means of ascertaining definitely the date of the end of this maximum advance are available, but the condition of the forest above the bare zone and the vegetation on the morainic deposits just mentioned would indicate that such a maximum occurred 25 or more years ago. The glacier had retreated from this farthest advanced position when it was first studied, in 1899. Still more advanced positions probably have not been occupied by the ice front for several centuries.

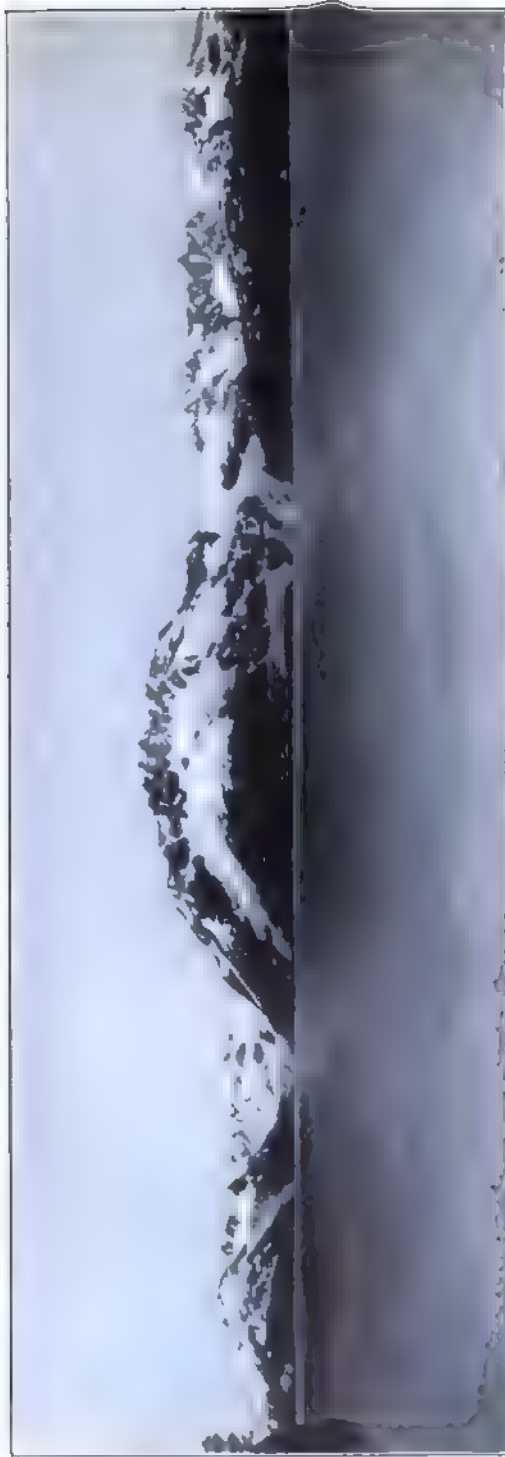
In 1905 and 1908 the frontal cliff of the glacier was estimated to be 250 feet high, but in 1909 the cliff appeared to have not more

¹ Gannett, Henry, *Nat. Geog. Mag.*, vol. 10, 1899, p. 510.



MAP OF HARRIMAN FIORD, PORT WELLS.

June 29 and 30, 1909. Occupied points indicated by circles, intersected points by crosses.



PANORAMA OF WEST SIDE OF HARRIMAN FJORD

From point D, Plate XVII. From right to left the glaciers are the Serpentine, Baker, Detached Suprius, and Catatract. The highest peak in the center is Mount Murr, and the peak above and just to the left of the boat is Mount Gilbert. These peaks are approximately 10,000 feet above sea level. The front of the Serpentine Glacier is 2 1/2 miles from the observer and the Surprise 5 1/2 miles. June 29, 1909. Photographs G 193 to G 196.



A. AUGUST 20, 1905.

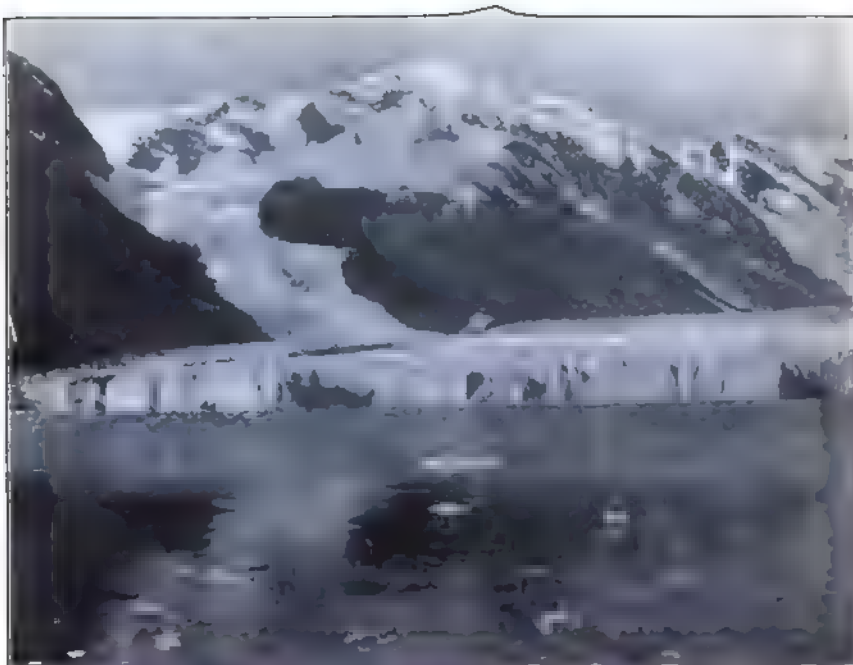
Photograph P 686.



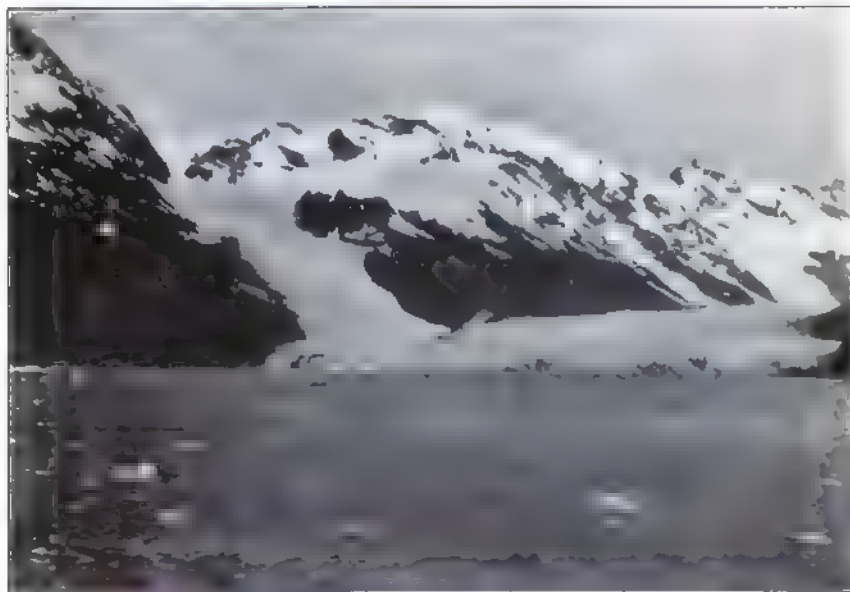
B. JUNE 29, 1909.

Photograph G 99.

EAST PART OF FRONT OF BARRY GLACIER.
From point A, Plate XVII.



A. AUGUST 20, 1905.
Photograph P 685.



B. JUNE 29, 1909
Photograph G 98.

CENTER AND WEST PART OF FRONT OF BARRY GLACIER.
In point A, Plate XVII. The waterfall at the left in B is just visible at the extreme left in A.

than half this height. The photographs of Plate XIX, taken in 1905 and 1909 from the same point, show considerable change in the ice front, especially in the altitude of the surface of the first feeder on the right, where it joins the main stream. The height of the bare zone on the east side near the present glacial front has been estimated as 400 feet above the ice of to-day. The thickness of the ice stream at its maximum recorded extent, therefore, was here 400 feet greater than at present. The front is now about 2.5 miles back of this maximum advance.

The position of the west part of the ice front in 1909 with reference to the first feeder (Cascade Glacier) and the noticeable waterfall from the hanging valley near the north end of the forested zone (Pl. XX, B) will assist in recording the amount of future fluctuation of this glacier.

SERPENTINE GLACIER.

The Serpentine Glacier is the first to reach tidewater west of the Barry Glacier. A considerable bare zone along the sides of the Serpentine Glacier and morainic accumulations in front of the glacier are evidences of an advance in comparatively recent years, but prior to 1899. The bare zone on the side is underlain by a distinct lateral moraine deposited at the time of this advance.

Our information concerning a still more recent retreat of the ice front consists in a few photographs taken in 1899, 1905, and 1909. The ice cliff in 1899¹ was probably higher and extended farther along tidewater than in 1909 (Pl. XVIII), and the eastern side of the glacier was more advanced at the earlier date. Photographs taken from a definite locality (point A, Pl. XVII) in 1905 and 1909 show that in the former year the west part of the front was more advanced than in 1909.

The Serpentine Glacier, then, had an advance a few years before 1899; in 1905 the position of the front of the ice was approximately the same as in 1899; and in 1909 the ice front was farther back than at either of the other dates. The retreat from 1905 to 1909 was perhaps a quarter of a mile, and from the advance before 1899 to the present time the glacier has retreated approximately half a mile on its center and eastern side and three-quarters of a mile on its western side. These distances are to be regarded only as estimates, for we did not study the front of this glacier close at hand, and most of our information comes from photographs.

BAKER GLACIER.

The Baker Glacier is named after Dr. Marcus Baker, editor of the Geographic dictionary of Alaska.² The névé and the ice stream of this glacier are practically one, and nearly the whole glacier is shown

¹ Alaska, vol. 1, Harriman Alaska Expedition, 1901, plate opposite p. 124; vol. 3, 1904, fig. 50.

² Bull. U. S. Geol. Survey No. 187, 1902; No. 299, 1906.

in Plate XXI, A. The surface of the Baker Glacier has a steep slope (shown in partial profile in Pl. XVIII), but near the sea the ice stream breaks over an almost vertical cliff, from which the ice falls and then accumulates near tidewater. A small tongue of the glacier, however, passes over this cliff and joins the ice below. These features can be seen in Plate XXI, A, which shows the conditions existing in 1909. In 1905 there was no ice at the base of the cliff, the small tongue of the glacier came downward only a short distance from the top of the cliff, and the ice front above the cliff was not so high nor so prominent as in 1909. The photographs taken in 1899 to which we have access show that the conditions existing then were very similar to those in 1909, but no front view of the glacier at the earlier date is available.

The Baker Glacier, therefore, shows a retreat between 1899 and 1905, but in 1909 the ice had advanced to, and probably beyond, its position of 10 years previous. Data are not at hand to measure the amount of this retreat and advance, but the distance is probably only a few hundred feet.

SURPRISE GLACIER.

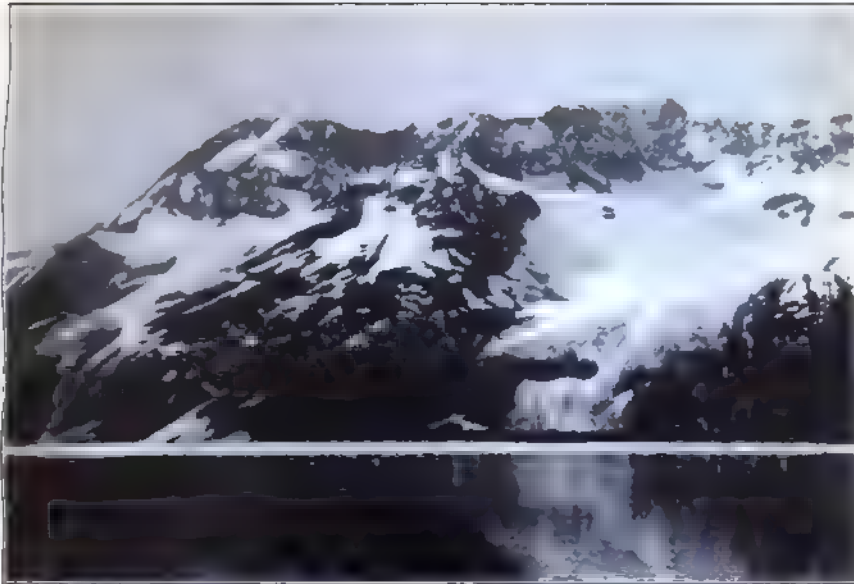
The Surprise Glacier reaches tidewater in a vertical cliff at the head of the west arm of Harriman Fiord. Along both sides of the glacier is a bare zone, which extends forward nearly to the Cataract Glacier. Gannett's map of Port Wells¹ shows the front of the Surprise Glacier practically at the point where the Cataract Glacier reaches tidewater. Photographs taken that year, however, show that the two glaciers were separated by a distance estimated to be a quarter of a mile. In 1909 the front of the Surprise Glacier was much farther (estimated at 1.1 miles) back than in 1899. How much of this retreat had taken place since 1905 is not clear, for our photograph of that year is indistinct; but it is certain that a considerable part of the retreat had occurred by 1905. A rock ledge, divided into two parts, projected from the front of the glacier near its south side in 1909. (See Pl. XXI, B.) Evidently this ledge would be covered by a slight advance of the ice; at least, so it appeared from our nearest point of observation to the Surprise Glacier, opposite the front of the Cataract Glacier. It is our recollection that no such ledge was visible in 1905.

The maximum advance of the Surprise Glacier in recent years is indicated by the bare zone; by 1899 the glacier had retreated about a tenth of a mile. This retreat was being continued in 1905, and in 1909 the glacier had retreated 1.1 miles from its position in 1899.

CATARACT GLACIER.

The Cataract is a small glacier descending a steep valley and reaching tidewater on the south side of the west arm of Harri-

¹ Alaska, vol. 3, Harriman Alaska Expedition, 1904, Pl. XIII.



A. BAKER GLACIER.

From point F, Plate XVII. Detached Glacier on left. June 29, 1909. Photograph G 105.



B. SURPRISE GLACIER.

From point F, Plate XVII. Detached Glacier on right. June 29, 1909. Photograph G 104.



A. CATARACT GLACIER.

June 30, 1909. Photograph G 107.



B. EAST PART OF FRONT OF HARRIMAN GLACIER.

From point H, Plate XVII. Dirty Glacier on left. June 29, 1909. Photograph G 106.

man Fiord. A comparison of Gannett's map of 1899¹ with our map (Pl. XVII) does not show any noticeable change in the position of the front of the glacier in the last 10 years. We have no photographs of this glacier taken before 1909, but those taken in that year (Pls. XVIII and XXII, A) will be of service in determining future advance or retreat. The latter view shows a narrow bare zone along the west side of the glacier, but the extent to which the shrubs have encroached upon this zone indicates that the ice stream has not in recent years (perhaps 25 years) been much larger than at present.

HARRIMAN GLACIER.

The Harriman is the trunk glacier of Harriman Fiord and comes to the water's edge at the southwest end of the fiord. The frontal cliff is estimated to be 300 feet high. The glacier has several feeders and comes from an extensive snow field from which emerge only a few peaks that are not permanently snow covered.

Photographs of the eastern part of the front of the Harriman Glacier, taken from point H, Plate XVII, in 1905 and in 1909 (Pl. XXII, B), show that this side of the glacier retreated approximately 700 feet between these dates. A comparison of an 1899 photograph² with our 1905 view indicates that between 1899 and 1905 the east side of the glacier retreated about half the above distance. As the two photographs were not taken from the same point this estimate of the retreat between 1899 and 1905 is only approximate. A careful examination of the western part of the ice front in 1909 from the position of a photograph taken in 1899³ showed no noticeable difference in the position of the glacier. In 1899 a considerable embayment existed in the eastern third of the front of this glacier, but this feature was not present in 1905 and 1909.

On the east side of Harriman Fiord scattered spruce trees extend southward to and just beyond the front of the Wedge Glacier, but do not reach so far south on the west side of the fiord. The absence of trees nearer the front of the Harriman Glacier seems to be due, as suggested by Gilbert,⁴ not to the glacier's having recently covered this area, but more likely to conditions unfavorable to forest growth. Though the glacier front may have advanced 2 miles farther north within the last century, it probably has not done so. In fact it is not likely that an extension of more than this distance has taken place within two or more centuries.

DIRTY GLACIER.

Dirty Glacier is a small ice stream reaching nearly to tidewater, three-fourths of a mile northeast of the east end of the front of Harri-

¹ Loc. cit.

² Idem, Pl. XV, upper figure.

³ Idem, Pl. XV, lower figure.

⁴ Idem, p. 96.

man Glacier. The smaller glacier comes from part of the extensive snow field that covers this end of the valley of Harriman Fiord. That portion of the Dirty Glacier which comes from the southwest lies in a shallow valley which is full, and in a few places more than full, of ice. This glacier has a medial moraine, which becomes more pronounced near the end and covers much of the glacier with dark débris, whence the name Dirty Glacier. In 1905 this glacier was a little more advanced than in 1909, and its tributary valley above mentioned overflowed more at the earlier date.

TOBOGGAN GLACIER.

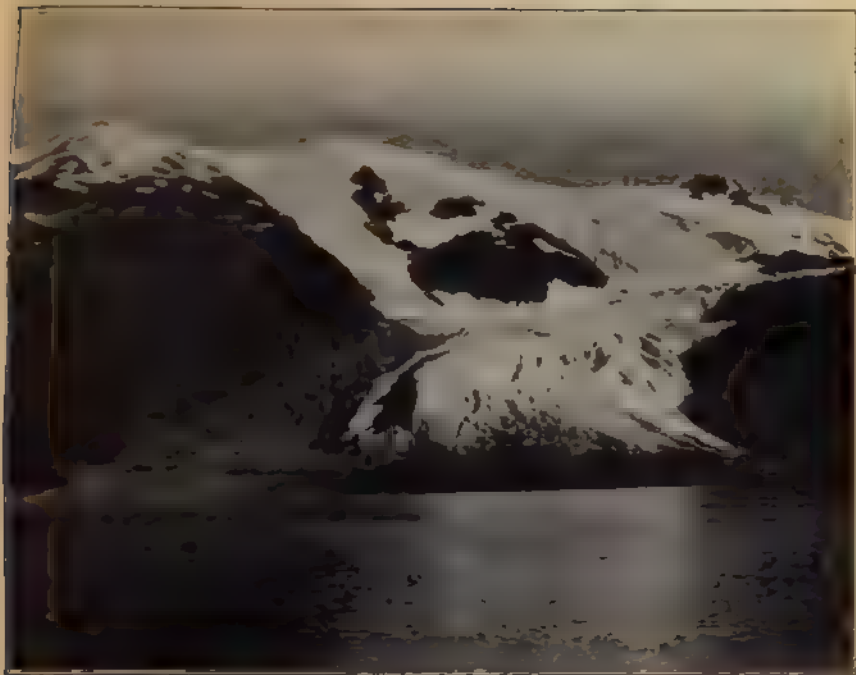
The Toboggan Glacier is a small ice stream coming from a rather extensive snow field that lies in the northern part of the peninsula separating Harriman Fiord from the lower part of Port Wells. This glacier has a marked bare zone along its sides, and its end deploys on a flat not far above sea level (Pl. XXIII, A). We visited this glacier on August 21, 1905, and on June 29, 1909. At the earlier date a small cairn was built on the outer or north end of the first projecting rock ridge on the right side of the valley going up, and the following bearings were taken: (1) To the extreme right end of front of glacier, S. 45° E.; (2) to the center or most advanced part of front of glacier, S. 63° E.; (3) to the extreme left end of front of glacier, S. 87° E. In 1909 bearing (1) was S. 55° E. and bearing (3) was S. 81° 30' E. In 1905 the center or most advanced part of the front—(2) above—was 723 feet (by pacing) from the cairn. Just at the extreme front of the ice at this time was a low rock ridge crossing the valley. In 1909 the most advanced part of the glacier was 252 feet farther back than in 1905. However, in 1909 a freshly deposited low moraine on the northern half of the plain in front of the glacier indicates that the ice some time between 1905 and 1909 had been about 400 feet in advance of its position in the earlier year. The map of 1899¹ shows that the glacier did not reach tidewater at that time, but the absence of vegetation on the bare zone at the side of the glacier and on the flat in front of it in 1905 (Pl. XXIII, A) shows that the ice front has occupied an advanced position, reaching practically to tidewater, at a very recent date, possibly, but not probably, later than 1899.

Photographs of glaciers of Harriman Fiord.

P 683. Distant view of Barry Glacier. August 20, 1905.

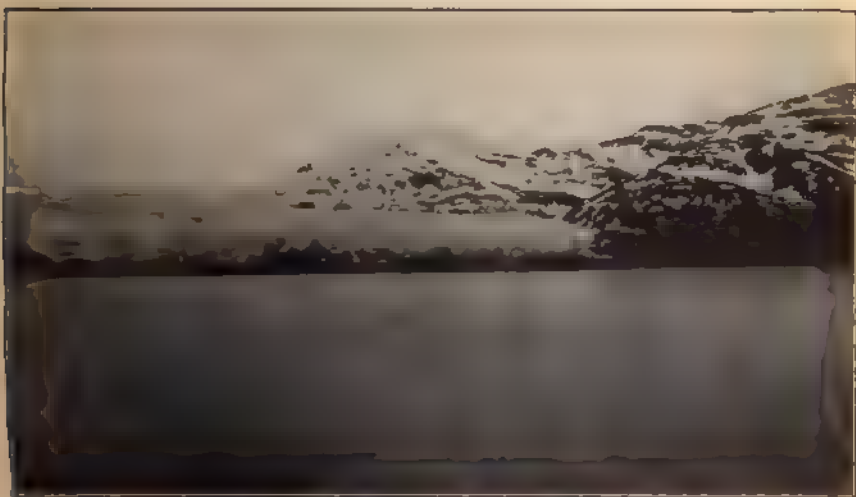
P. 684 and 685. No. 685 is here reproduced as Plate XX, A. Front of Barry Glacier from point A, Plate XVII. August 20, 1905. Point A is about 80 feet above sea level, on a mossy bench 50 to 100 feet wide, on the most northerly part of Point Doran. From this station the ground drops very steeply to tidewater. From the same position the following photographs have been taken: P 686 and 687, G 98-100, G 108.

¹ Alaska, vol. 3, Harriman Alaska Expedition, 1904, Pl. XIII.



A TOBOGGAN GLACIER

August 20, 1905 Photograph P 731



B WEST PART OF FRONT OF TEBENKOF GLACIER

From point A figure 5 July 5, 1909 Photograph G 13

P 686. Here reproduced as Plate XIX, *A*. East side of front of Barry Glacier from point A, Plate XVII. August 20, 1905.

P 687. Serpentine, Baker, and Surprise glaciers from point A, Plate XVII. August 20, 1905.

P 688. Distant view of Harriman Glacier. August 20, 1905.

P 689. South side of front of Harriman Glacier and south side of front of Dirty Glacier from point H, Plate XVII. August 20, 1905. Point H is the top of a dark-colored conglomerate boulder about 12 feet high, standing at high-tide line on the west side of Harriman Fiord on the southern part of the fan from the Roaring Glacier. This boulder is plainly visible from a boat coasting along the shore. From the same position the following photographs have been taken. P 690 and 691; G 106, G 199 and 200.

P 690 and 691. Front of Harriman Glacier from point H, Plate XVII. August 20, 1905.

P 731. Here reproduced as Plate XXIII, *A*. Toboggan Glacier. August 20, 1905.

P 732. Hanging Glacier (probably the Roaring Glacier). August 20, 1905.

P 733. Baker Glacier. August 20, 1905.

G 60. East part of front of Barry Glacier. August 11, 1908.

G 61. West part of front of Barry Glacier. August 11, 1908.

G 72. West part of front of Barry Glacier. August 11, 1908.

G 97. Mountains north and west of Harriman Fiord from Esther Passage. June 28, 1909. The highest dark peak in center of right half of photograph is Mount Gilbert; Mount Muir is on the left. See G 192.

G 98. Here reproduced as Plate XX, *B*. West side of Barry Glacier from point A, Plate XVII. June 29, 1909. See under P 684.

G 99. Here reproduced as Plate XIX, *B*. East side of Barry Glacier from point A, Plate XVII. June 29, 1909. See under P 684.

G 100. Serpentine, Baker, and Surprise glaciers from point A, Plate XVII. June 29, 1909. See under P 684.

G 101. West side of Barry Glacier, from point C, Plate XVII. June 29, 1909. Point C is about 60 feet above sea level on the second rock point north of the long gravel beach on the east side of the bay on which the glacier is situated. This point is composed chiefly of hard slate, much smoothed and rounded by recent glaciation.

G 102. General view of Barry Glacier. June 29, 1909.

G 103. Serpentine Glacier from point D, Plate XVII. June 29, 1909. Point D is about 60 feet above sea level on a small bench, on a fairly steep mossy slope, on the southeast side of Harriman Fiord, 1 mile northeast of the front of the Toboggan Glacier. Photographs G 193-196 also were taken from this station.

G 104. Here reproduced as Plate XXI, *B*. Surprise Glacier from point F, Plate XVII. June 29, 1909. Point F is about 100 feet above sea level, on a mossy bench a mile southwest of the gravel fan in front of the Toboggan Glacier. Behind (southeast of) this station is a small depression opening to the southwest, and northwest of the station the land descends steeply to the sea. Photographs G 197 and 198 also were taken from this station.

G 105. Here reproduced as Plate XXI, *A*. Baker Glacier from point F, Plate XVII. June 29, 1909.

G 106. Here reproduced as Plate XXII, *B*. East side of front of Harriman Glacier from point H, Plate XVII; Dirty Glacier at left. June 29, 1909. See under P 689.

G 107. Here reproduced as Plate XXII, *A*. Cataract Glacier. June 30, 1909.

G 108. West side of Barry Glacier from point A, Plate XVII. June 30, 1909. See under P 684.

G 192. Mountains west of Harriman Fiord, from Esther Passage; Mount Muir in central background. June 28, 1909. See G 97.

G 193 to 196. Here reproduced as Plate XVIII. Panorama showing Cataract, Surprise, Baker, and Serpentine glaciers from point D, Plate XVII. June 29, 1909. See under G 103.

G 197 and 198. Panorama of Serpentine and Baker glaciers, from point F, Plate XVII. June 29, 1909. See under G 104.

G 199 and 200. Panorama of Harriman Glacier, from point H, Plate XVII; Dirty Glacier on left. June 29, 1909. See under P 689.

PASSAGE CANAL.

There are no glaciers that reach tidewater on Passage Canal, although several approach the canal from the north, west, and southwest. The Seth and Billings glaciers descend southward from the same general ice field that feeds the Harriman Glacier and end about a mile from the north shore of Passage Canal. Northwest of the upper part of the canal are at least three small glaciers draining into this body of water. The most important ice stream near the canal is the Portage Glacier, described below.

A hasty visit was made by our party to the head of Passage Canal (Portage Bay) on July 3, 1909. The eastern end of Portage Glacier was too far distant from the shore and too much hidden by a low, bare rocky point in the gravel-filled valley to permit careful observations. It is probable that no large part of the glacier debouches on the east side of the divide between Passage Canal and Turnagain Arm, for no large glacial stream enters the head of the canal. A trail over this glacier was much used for travel between Prince William Sound and Cook Inlet before the Seward-Sunrise trail was opened.

In 1898 Mendenhall visited the head of this bay and made the following interesting observations:¹

The isthmus which connects Kenai Peninsula with the mainland is only about 12 or 13 miles broad from tidewater to tidewater and probably stands but little above sea level, but for 5 miles of this distance it is buried under a glacier, which flows from the high mountains of the peninsula to the south. This glacier at its highest point is about 1,000 feet above tide, and can be crossed in a few hours from the open waters of Portage Bay by prospectors or others who desire to reach Sunrise City or the headwaters of Cook Inlet before this body of water is open to navigation in the spring. For more than 100 years it has been used as a route, first by the Russian and Indian traders, and later by miners, who usually cross it without difficulty in the winter or early spring. In the summer the crevasses open, and it is but rarely used, especially since at that season the all-water route is so much easier and cheaper.

* * * * *

Portage Bay receives several glacial tributaries. Southwest of Point Pigot, which separates this bay from Port Wells, is the mouth of Blackstone Bay, which receives Blackstone Glacier from the south. Both the bay and glacier are named for a miner who lost his life there a few years ago.

Three glaciers approach sea level at the head of Portage Bay. One of these is Portage Glacier, whose foot is about a mile back from the beach. Its outlet is toward

¹ Mendenhall, W. C., A reconnaissance from Resurrection Bay to the Tanana River, Alaska, in 1898. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 273, 325, 326.

Turnagain Arm, and it probably has never discharged into Prince William Sound. A second glacier spills over the mountain rim 2,000 feet above tide in an ice cataract on the southeast side of the bay. The third and smallest, now rapidly retreating, flows down from the mountains to the northwest, and has until very recently reached across the belt of gravel delta which separates the foot of the mountain slope from the head of the bay, but has now dwindled until the portion reaching the gravel plain is small and composed wholly of white ice.

This little glacier illustrates very well the rapidity of the ice retreat and shows us the processes whose results only remain in portions of the New England landscape. One quarter of a mile out from its present terminus is a hillock 220 feet high and half a mile long, with its longer axis parallel with the glacier front. It is now separated from this latter by an open valley paved with boulders. At first sight this elevation was supposed to be a simple terminal moraine, but upon examination it proved to consist mostly of ice deeply covered with angular *débris*, which is also disseminated through it. This remnant of the glacier seems to stand near a position which the ice front occupied long enough to become covered by a sufficiently thick mantle of protective *débris*, so that melting was not so rapid as in the less well-protected part of the glacier just back of the front. The separation from the glacier was probably facilitated by the exit of the subglacial stream through a tunnel back of the protecting mantle. The combined melting from above and below soon removed this neck, leaving the former front isolated as it stands to-day. Since its isolation it has been shrinking each summer and now occupies less than half of its original area. Around its seaward side is a belt of rough ground of slight relief covered with angular and unsorted material, which has been let down into position by the melting of the ice front. The outer rim of this zone is somewhat higher than the inner portion, giving it the form of a shallow amphitheater facing the remnant of the glacier. The stability of the position of maximum advance for a short time due to the balance between flow and melting at the front accounts for the slightly greater accumulation there and the building of the low rubble wall.

These recent glacial details of topography are the more striking since they are built upon a smooth water-laid deposit of relatively fine material. This delta is of the type which usually forms before glaciers in these fiords and gives about the only level areas to be found near sea level in a region of sharp topographic forms. At its outer margin, a short distance seaward from low-tide level, the delta slopes abruptly to the profound depths so often found in these inlets.

BLACKSTONE BAY.

GENERAL FEATURES.

The early maps of the shore line between Point Culross and Passage Canal were inaccurate, probably because they were made by explorers who had not followed closely the intricacies of the shore line. Blackstone Bay, except its head, was fairly well shown on these maps, but Cochrane Bay was poorly delineated, and Culross Passage was not shown at all. Vancouver's map (1794) of this district and Tebenkof's (1849) have formed the basis for other and later maps. Applegate's map of 1887¹ adds some detail and is the first map to which we have access that indicates the Tebenkof Glacier. Culross Passage, behind Point Culross, was reported by the United States Geological

¹ Davidson, George, The glaciers of Alaska that are shown on Russian charts or mentioned in older narratives: *Trans. and Proc. Geog. Soc. Pacific*, 2d ser., vol. 3, 1904, map 11.

Survey reconnaissance of 1905 and indicated on chart No. 8502 of the United States Coast and Geodetic Survey in 1907. A more detailed map of this district has now been published.¹ (See also Pl. I and fig. 5 of the present report.)

On the maps of Vancouver and Tebenkof, "ice and snow," which undoubtedly refers to a glacier discharging into the sea, are shown at the head of Cochrane Bay, and the accompanying description² indicates the same fact. There was evidently a mistake in locating this glacier. It should be shown at the head of the next bay west (Blackstone Bay), for there is no evidence that in historic time a glacier occupied the head of Cochrane Bay. The land at the head of this bay is comparatively low, and extends south-southwest to Port Nellie Juan. The glacier seen by Vancouver was evidently the Blackstone Glacier, which reaches tidewater at the head of Blackstone Bay.

Our information concerning the glaciers of Blackstone Bay was gained by a hurried reconnaissance on July 5, 1909. No definite information concerning the positions of the fronts of these glaciers at an earlier date is extant.

TEBENKOF GLACIER.

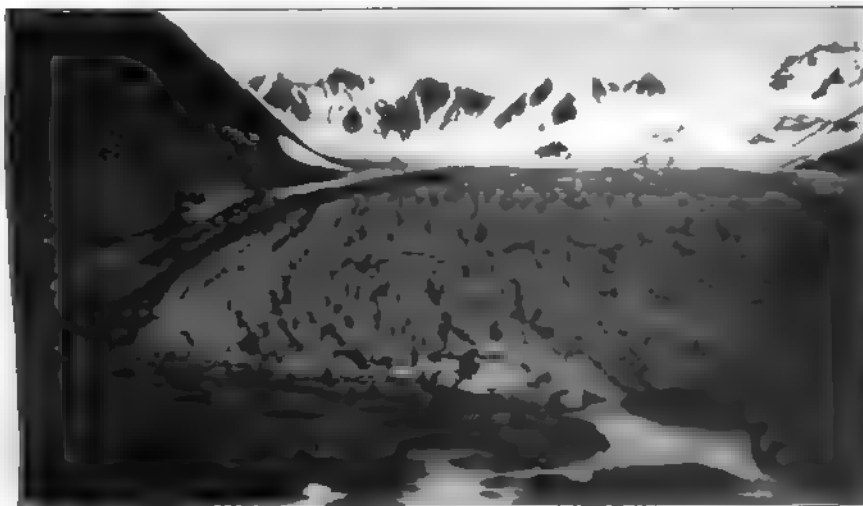
The front of the Tebenkof Glacier comes within about a mile and a quarter of the shore of a small bay on the south side of the entrance to Blackstone Bay and is named after Capt. M. D. Tebenkof, governor of Russian America from 1845 to 1850. This glacier is an ice stream $1\frac{1}{2}$ to 2 miles wide, which flows northward in a valley parallel to Blackstone Bay. The ice field of this glacier is continuous with that of the Blackstone Glacier. The Tebenkof Glacier has a comparatively low slope, and its front lies on a flat of glacial débris. This flat in places is covered with a forest, which would indicate that the glacier had not reached tidewater in the last century and probably not in a considerably longer period. Along each part of the front of the glacier is a bare zone, estimated to be 500 feet wide, which has apparently been covered by a recent advance of the ice. The date of this advance, which probably destroyed part of the forest at the west edge of the glacier, is uncertain, but the absence of vegetation on the bare zone indicates that it probably took place within the last 10 or 15 years. The front of the glacier was not visited, so nothing is known of the distance between the present front and this recent advanced position, which represents the maximum advance since the growth of the present forest. The position of the front of the glacier in 1909 is shown in Plates XXIII, *B*, and XXIV, *A*.

¹ Grant, U. S., and Higgins, D. F., Reconnaissance of the geology and mineral resources of Prince William Sound, Alaska: Bull. U. S. Geol. Survey No. 442, 1910, Pl. II.

² Quoted by Davidson, op. cit., p. 23.



1. EAST PART OF FRONT OF TEBENKOF GLACIER.
From point B, figure 5. July 5, 1909. Photograph G 114



1. SPLIT GLACIER.
From point F, figure 15. August 2, 1909. Photograph G 232.

BLACKSTONE GLACIER.

The Blackstone Glacier surrounds the head of Blackstone Bay, sending down from a very extensive ice field no less than ten ice

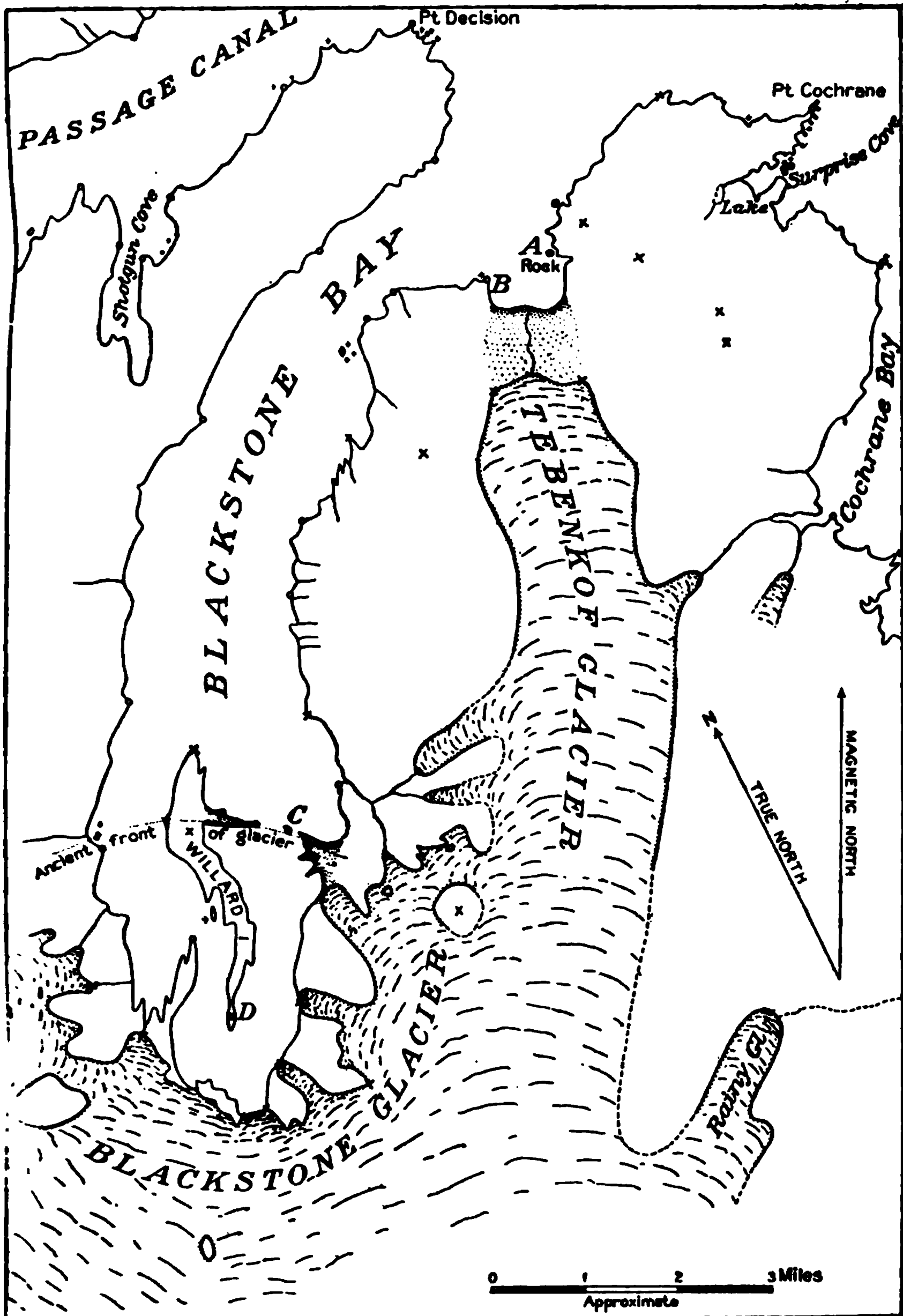


FIGURE 5.—Map of Blackstone Bay July 5, 1909. Occupied points indicated by circles, intersected points by crosses.

streams (fig. 5). Two of these streams have discharging cliffs at sea level, and two others on the east side of the bay reach just to high

tide on gravel aprons formed at the lower ends of the alpine valleys occupied by the glaciers. The earlier maps show the south end of Willard Island covered with ice, but as the south end of the island has a very deceptive appearance till one comes close to it and as the size and density of the vegetation on the island indicate several decades of growth, it is altogether probable that the ice has not been as far north as Willard Island within the time of which we have record, namely, since 1794.

There is very good evidence, however, that much earlier, perhaps two centuries ago, the front of the Blackstone Glacier did extend well up to the north end of Willard Island. In figure 5 a line shows the approximate position of this ancient ice front. North of this line the island is heavily forested, but south of it the character of the cover changes abruptly, and there consists only of sparse fir trees and a dense growth of shrubbery. On the west side of the island a small gravel point marks the position of the old terminal moraine. No precise location for the old front could be determined on the west side of the bay. On the east side of both island and bay is a notable accumulation of morainal material extending across from the island to the mainland, under a shallow channel in which tidal currents run very swiftly. The two points south of point C in figure 5 may be modified remains of two recessional moraines. Although the island itself is very sparsely timbered south of the old ice front, the gravel deposits on the east side of the bay are heavily timbered. The development of sparse and dense forests in approximately the same period is doubtless due to the more favorable conditions for forestation upon the gravel than on the bare glaciated rock of the island.

The scenery in view from the small eminence on the south end of Willard Island is nearly as wild and desolate as that at the head of Harriman Fiord. To the south, from west to east, a vast ice field almost barren of nunataks stretches back to a brilliant white sky line. From the central mass many tongues of ice lap down over the smooth rock slopes or break off into the sea. It requires little effort of the imagination to picture all these tongues coalesced into one giant ice stream filling the whole head of the bay and extending far down over Willard Island to the ancient moraine.

Photographs of glaciers of Blackstone Bay.

G 112. Front of Tebenkof Glacier. July 5, 1909.

G 113. Here reproduced as Plate XXIII, *B*. Front and west side of Tebenkof Glacier from point A, figure 5. July 5, 1909. Point A is on the top of a rocky islet or reef at the east side of the entrance to the small bay on the south side of, and near the lower part of, Blackstone Bay.

G 114. Here reproduced as Plate XXIV, *A*. East side of front of Tebenkof Glacier from point B, figure 5. July 5, 1909. Point B is on the end of the point at the west side of the entrance to the small bay on the south side and near the lower part of Blackstone Bay.

G 115. Northerly lobe of Blackstone Glacier, which does not reach tidewater, from point C, figure 5. July 5, 1909. Point C is on a low, treeless island near the east shore of Blackstone Bay and about 3 miles north of the head of the bay.

G 116. Main part of front of Blackstone Glacier, from point C, figure 5. July 5, 1909.

G 213 and 214. Panorama of front of Blackstone Glacier from point D, figure 5. July 5, 1909. Point D is the top of the small round hill, 60 or 70 feet above the sea, on the south end of Willard Island. It is about 200 yards north of the southern extremity of the island.

PORT NELLIE JUAN.

GENERAL FEATURES.

Port Nellie Juan (Pl. XXV), sometimes called Kings Bay after a prospector who had a cabin near its head, is the most extensive embayment on the west coast of Prince William Sound. The long southwestern arm of Port Nellie Juan was not shown on the earlier maps, nor were the glaciers of this port indicated. The first map showing the details of the upper half of this bay was made by S. Applegate in 1887.¹ We visited Port Nellie Juan on August 8 and 9, 1908. The accompanying map and the information obtained in August, 1908, embody all the data known to us concerning the glaciers of this port. The glaciers on the west side of Port Nellie Juan were not seen at close range, so the locations of their fronts (Pl. XXV) are only approximate.

South of the central part and east of the southern part of Port Nellie Juan is a snow field of unknown but considerable extent. Several glaciers flow north and west from this field, and two of them, the Nellie Juan and the Falling glaciers, reach tidewater. On the west side of the southern part of the port are other glaciers, one of which, the Taylor, reaches sea level. At the head of Port Nellie Juan the water is shallow and is kept very muddy by Kings and Nellie Juan rivers and smaller streams bringing charges of silt from the neighboring glaciers. These streams come from what is probably one of the largest ice-covered areas of the Kenai Peninsula.

ULTRAMARINE GLACIER.

The Ultramarine Glacier, so named because of the clear blue color of the ice near its end, is situated at the head of Blue Fiord, the second deep indentation from the entrance in the southeastern coast of Port Nellie Juan. The glacier comes within about a quarter of a mile of tidewater, and the western part of its front extends beyond the eastern two-thirds and rests on a glacial flat. The eastern part of the front rests on a rock ridge about 300 feet above the sea. On this ridge is a marked bare zone, and there is another at the side of the glacier. The front of the glacier was not visited, but at a distance this bare zone appeared as if the ice had retreated from it in

¹ Davidson, George, op. cit., pp. 26-27, map 11.

the last two or three years. Applegate's map referred to above indicates that the glacier in 1887 reached to tidewater along its whole front. The forest in front of the eastern part of the glacier shows that this part could not have extended so far. The western part may have reached tidewater at that time, but even this is doubtful. Our observations on this glacier were made at a distance of about a mile and a half.

NELLIE JUAN GLACIER.

The Nellie Juan Glacier (Pls. XXV and XXVI) is the largest, at least in breadth of front, on Port Nellie Juan, after which it is named. The front of the glacier is distinctly in view from the entrance of the port and rests on a gravel beach, most of which is covered by high tide; near the center of the front the ice is bathed even by low-tide water. On each side of the lower part of the glacier is a distinct bare zone of smoothed granite, 100 to 500 feet wide, which ends abruptly at the edge of a forest-covered tract. This zone is prominently developed on a granite knob, almost an island, at the west side of the glacial front. Crossing the top of this knob is a small moraine (at point A, Pl. XXV) from 1 to 10 feet high and 5 to 30 feet wide. This moraine contains fragments of dead wood, and just north of it is an area of scattered trees some of which are a foot in diameter. South of the moraine is some vegetation—moss, grass, alders 5 feet high, and a few spruce trees 4 feet high. Most of the vegetation disappears halfway from the moraine to the ice front. From the extreme summit (point A, Pl. XXV) of the above-mentioned granite knob the nearest point of the moraine is 48 feet distant in a direction S. 10° W. From the same summit the extreme front of the glacier bears S. 74° E., and the nearest point of the ice is 500 feet S. 13° W.

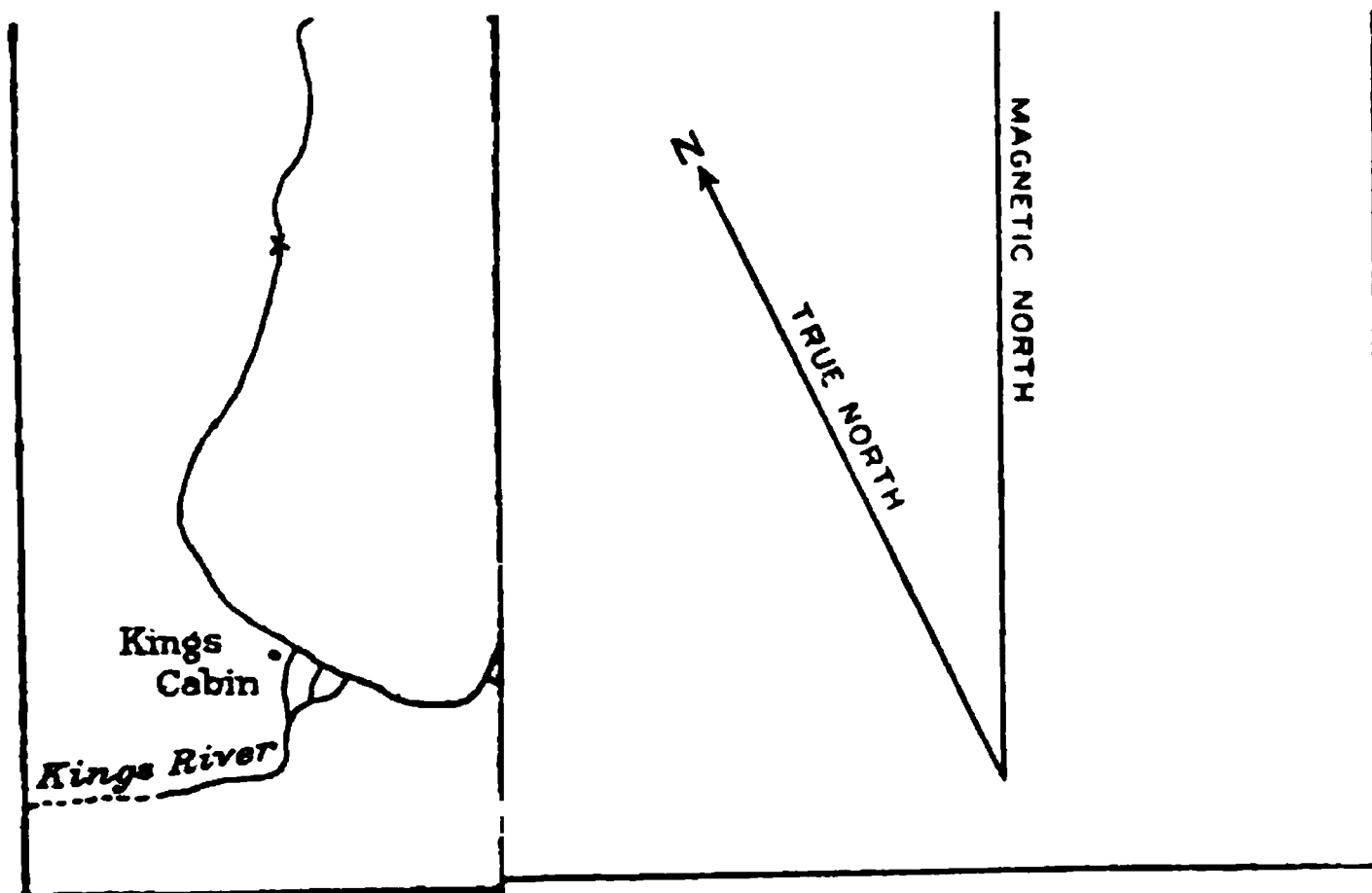
The moraine noted above marks the farthest advance of the ice since the growth of the present forest—that is, for a century, and most probably for two or three centuries. This maximum advance in historical time occurred at least 20 years ago and probably much earlier.

FALLING GLACIER.

Falling Glacier is a small ice stream on the east side of the southern stretch of Port Nellie Juan. On August 8, 1908, a small tongue from the ice just reached the sea. In front of the glacier, however, is a bare zone, which has been covered by the ice within a very few years. When this zone was covered the glacier had a tidal front of about 1,200 feet.

TAYLOR GLACIER.

The Taylor Glacier is the only one that reaches tidewater on the west shore of Port Nellie Juan. This glacier has a medial moraine

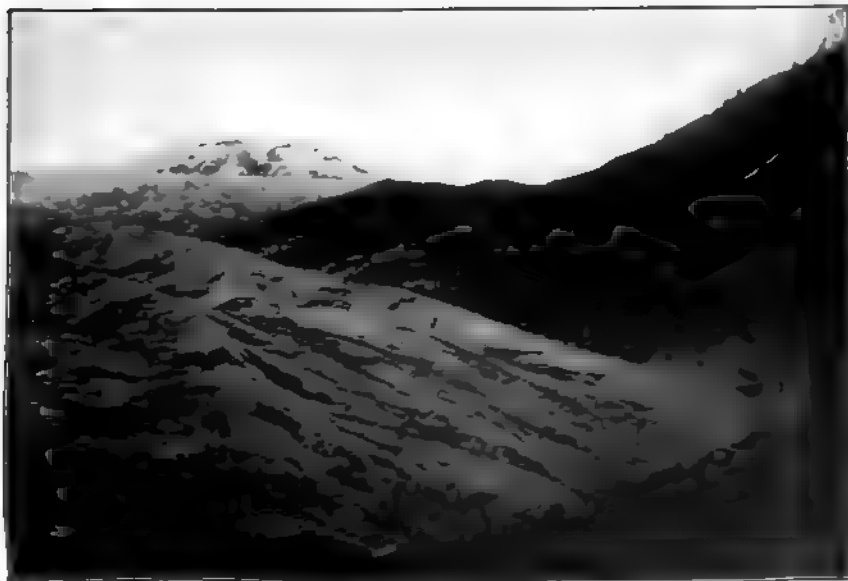


bid boat traverse.



A. FRONT OF NELLIE JUAN GLACIER.

From point A, Plate XXV, the summit of a granite knob at the west side of the glacier front. August 8, 1908. Photograph G 51



B. WEST SIDE OF NELLIE JUAN GLACIER.

From point A, Plate XXV. August 8, 1908. Photograph G 52

and a marked bare zone along each side of its lower end. We did not examine the Taylor Glacier carefully and have little information concerning it other than that shown on the map and in three of the photographs listed below. The freshness of the bare zone indicates that the maximum advance of the glacier since the present forest has grown up took place only a very few years ago. In this advance the front of the glacier reached a line about a quarter of a mile beyond its present position and had an extent of a mile along tidewater. Applegate's map of 1887 shows a glacier, probably the Taylor, reaching not quite to the water.

Photographs of glaciers of Port Nellie Juan.

G 49. Nellie Juan Glacier from northwest end of island near east shore of Port Nellie Juan, about 5 miles north-northeast of the glacier. August 8, 1908.

G 50. Ultramarine Glacier from distance of about 1½ miles. August 8, 1908.

G 51. Here reproduced as Plate XXVI, A. Front of Nellie Juan Glacier from point A, Plate XXV. August 8, 1908. Point A is about 175 feet above sea level on the extreme top of a granite knob, almost an island, on the west side of the front of the glacier.

G 52. Here reproduced as Plate XXVI, B. West side of Nellie Juan Glacier from point A, Plate XXV. August 8, 1908.

G 53. Moraine, forested and forestless zones at point A, Plate XXV. August 8, 1908.

G 54. A more distant view of same locality as No. G 53.

G 55. Nellie Juan Glacier from a point about 2 miles north. August 8, 1908.

G 56. Taylor Glacier from small island on east side of Port Nellie Juan and about one-half mile south of entrance to the upper part of the port. August 8, 1908.

G 57. Front of Falling Glacier. August 8, 1908.

G 58. Front of Taylor Glacier. August 9, 1908.

G 59. Front of Taylor Glacier. August 9, 1908.

ICY BAY.

GENERAL FEATURES.

No glaciers exist near tidewater on Prince William Sound between Port Nellie Juan and Icy Bay (fig. 6), which is a fiord extending from the southwestern part of the sound. The axis of Icy Bay runs northeast and southwest, and the fiord is approximately 10 miles long. This bay has been represented on maps as about 4 miles long and as having an east and west axis. It was not until after the United States Geological Survey reconnaissance of 1908 that the bay was delineated with approximate accuracy.¹ The errors in mapping arose from the fact that Vancouver's representation of this bay was followed in later maps, and he had reported,² as quoted by Davidson, that the bay was "terminated by a compact body of ice that descended from high perpendicular cliffs to the water side." At that date (1794) it is very probable that the glaciers in Nassau

¹ Grant, U. S., and Higgins, D. F., Copper mining and prospecting on Prince William Sound: Bull. U. S. Geol. Survey No. 379, 1909, Pl. IV.

² Trans. and Proc. Geog. Soc. Pacific, 2d ser., vol. 3, 1904, p. 23.

Fiord, the large bay on the northwest side of Icy Bay, completely filled that fiord and extended into, but not across, the main part of Icy Bay. This, together with the extensive discharge of ice from these glaciers (combined as one), probably prevented close inspection of the bay and the discovery of its upper part.

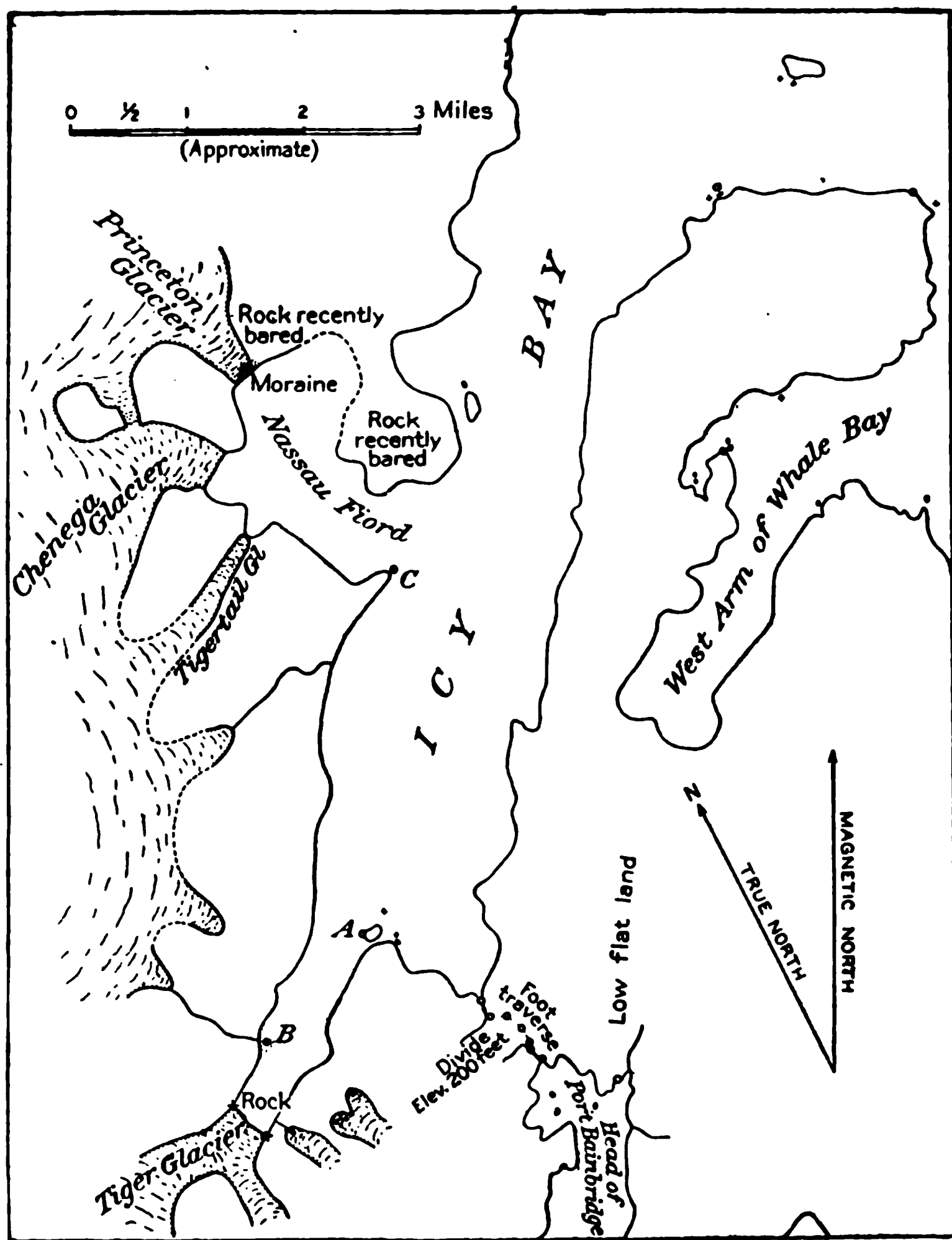


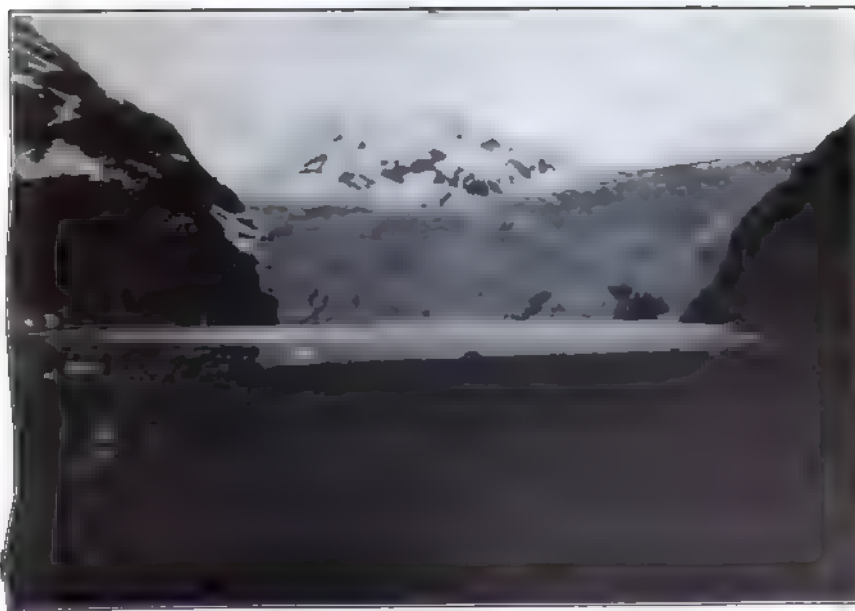
FIGURE 6.—Map of Icy Bay August 5, 1908. Occupied points indicated by circles; intersected points by crosses.

Our visit to Icy Bay was on August 5, 1908, when we made a hasty reconnaissance of the bay, came within half a mile of the Tiger Glacier, and obtained our information concerning the Chenega and Princeton glaciers from the rock islet (point C, fig. 6) at the entrance to Nassau Fiord. In the following year Icy Bay was visited by the George W. Perkins party. The names here used, except the name



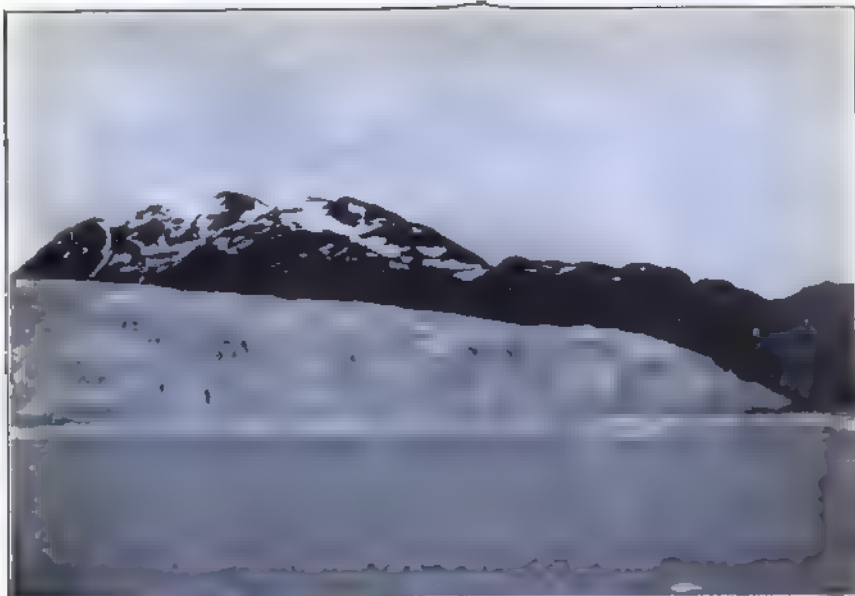
A. CHENEGA AND PRINCETON GLACIERS.

From point C, figure 6. Chenega Glacier on left. August 5, 1908. Photograph G 48.

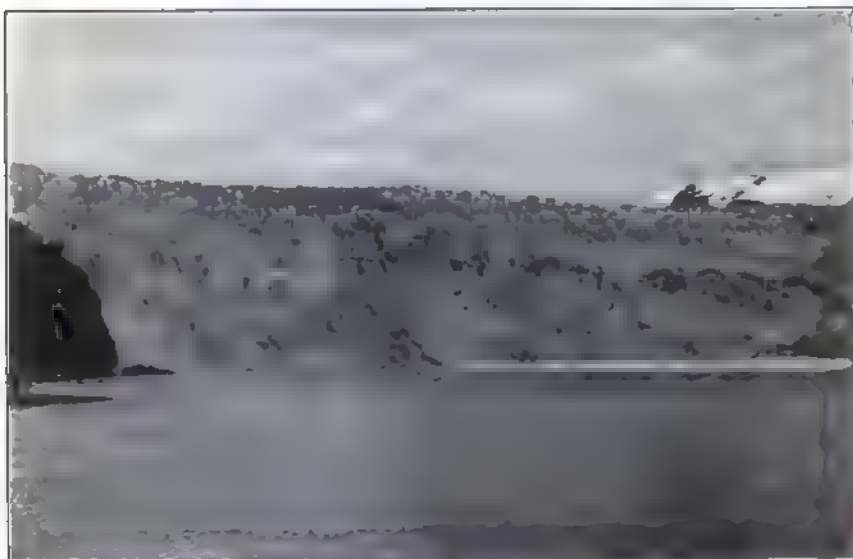


B. TIGER GLACIER.

From point B, figure 6. August 6, 1908. Photograph G 45.



A. NORTH PART.



B. SOUTH PART.

FRONT OF CHENEGA GLACIER.

August 19, 1909. From photographs by W. E. Carlin for the George W. Perkins party.

Chenega Glacier and the name Princeton for the glacier immediately northeast of the Chenega, are those proposed by that party. The Chenega, the main discharging glacier in Icy Bay, has long been known locally by this name, and the name has been published at least three times.¹

PRINCETON GLACIER.

The Princeton Glacier is the most northeasterly ice stream discharging into Nassau Fiord of Icy Bay. The glacier has apparently a massive moraine along most of its front and reaches tide water only at its western side (Pl. XXVII, A). This glacier is not discharging rapidly. Further particulars concerning it will be found under the Chenega Glacier.

CHENEGA GLACIER.

The Chenega Glacier reaches tidewater at the head of Nassau Fiord, is discharging abundantly, and is the ice stream which furnishes most of the floating ice so common in and about the mouth of Icy Bay. From the top of a small rock island at the entrance to Nassau Fiord (point C, fig. 6) both the Chenega and Princeton glaciers are in full view (Pl. XXVII, A). From this point true bearings were taken as follows: (1) Extreme right of front of Princeton Glacier, N. 8° W.; (2) extreme left of front of same glacier, N. 19° W.; (3) extreme right of front of Chenega Glacier, N. 28° W.; the extreme left of the same glacier is not in view from this point.

On August 19, 1909, the George W. Perkins party approached much nearer to the Chenega Glacier. Photographs made by members of this party show much less floating ice in Nassau Fiord than was present in August of the preceding year. They obtained good views of the front of this glacier, which are here reproduced, through the courtesy of Messrs. Perkins and Carlin, in Plate XXVIII.

The rock surface about the entrance to Nassau Fiord has been recently glaciated and no forest has developed on it. The entrance to this fiord as well as the peninsula at the north side of the entrance were covered by ice undoubtedly within the last 100 years and quite possibly within a much shorter period. The Indians living at the settlement of Chenega have a tradition that the Chenega Glacier reached to the mouth of Icy Bay about 100 years ago, but the growth of the forest about the bay and even well up past the mouth of Nassau Fiord precludes this idea. The tradition would refer more reasonably to the mouth of the northern arm (Nassau Fiord) than to Icy Bay itself.

¹ Bull. U. S. Geol. Survey No. 284, 1906, p. 79; Bull. U. S. Geol. Survey No. 299, 1906, p. 172; U. S. Coast and Geod. Survey chart No. 8550, Aug., 1909.

TIGER GLACIER.

The Tiger Glacier reaches tidewater at the extreme head of Icy Bay. The front of the glacier is steep and the eastern part of it was discharging in 1908 with fair rapidity. The western half of the front shows a ledge of rock just emerging from under the ice (Pl. XXVII, *B*). In a photograph taken by W. E. Carlin, of the George W. Perkins party, on August 19, 1909, this ledge is completely covered by an advance of the glacier. The amount of this advance can not be determined from the photographs, but it probably does not exceed a few hundred feet and may be less than 100 feet.

Photographs of glaciers of Icy Bay.

G 44. Tiger Glacier from point A, figure 6. August 5, 1908. Point A is on the western end of the largest island at the east side of the entrance to the upper narrow portion of Icy Bay.

G 45. Here reproduced as Plate XXVII, *B*. Tiger Glacier from point B, figure 6. August 5, 1908. Point B is on the flat, exposed at low tide, at the mouth of a small glacial stream entering the upper narrow portion of Icy Bay about $1\frac{1}{2}$ miles southwest of point A.

G 46 and 47. Panorama of Chenega and Princeton glaciers, from point C, figure 6. August 5, 1908. Point C is the top of a rock islet at the southwest side of the entrance to Nassau Fiord.

G 48. Here reproduced as Plate XXVII, *A*. Chenega and Princeton glaciers, from point C, figure 6. August 5, 1908.

BAINBRIDGE GLACIER.

The Bainbridge Glacier is the only tidewater glacier on Port Bainbridge. A mile north of this glacier is a smaller one ending about 500 feet above sea level. The Bainbridge Glacier does not appear on the earlier maps, although it is in view from ships passing Point Elrington. The first map known to us that shows this glacier is a small one published in 1906.¹ The glacier had, however, been known long before that date and the name Bainbridge is in common use locally. We saw the glacier from a distance in 1905 and on August 3, 1908, visited it and mapped its front (fig. 7).

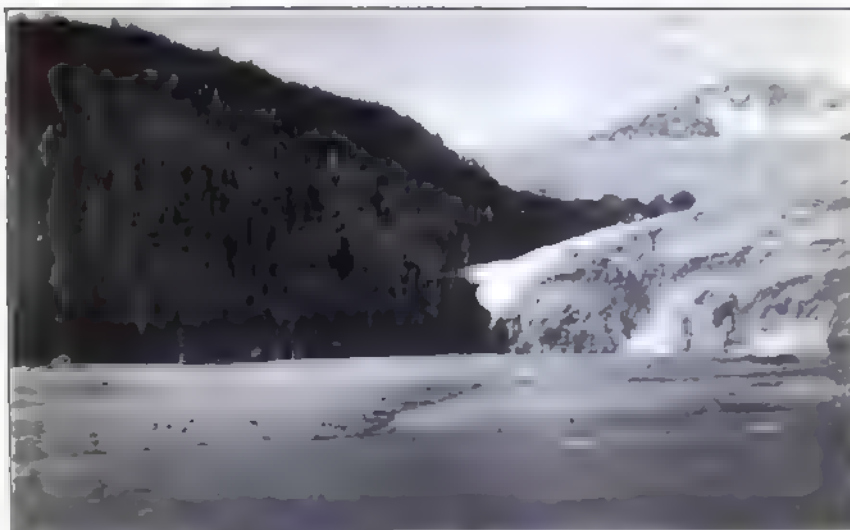
The Bainbridge Glacier ends on a glacial flat, and the central part of the front is reached by the usual high tide, so that an ice cliff is developed along this part of the front. This cliff is approximately 100 feet in height, and its top is composed of ragged ice pinnacles singularly free from débris and showing in sunlight a beautiful play of greenish-blue colors. Near the northern part of the ice front is a push moraine, 10 feet high, which in places stands directly at the edge of the ice and at other places is as much as 60 feet away. This moraine is very fresh and probably was formed in the summer of 1908. The moraine includes fragments of trees and toward the

¹ Grant, U. S., Copper and other mineral resources of Prince William Sound: Bull. U. S. Geol. Survey No. 284, 1906, p. 79.



A. FRONT OF BAINBRIDGE GLACIER.

From point A, figure 7. August 3, 1908. Photograph G 40.



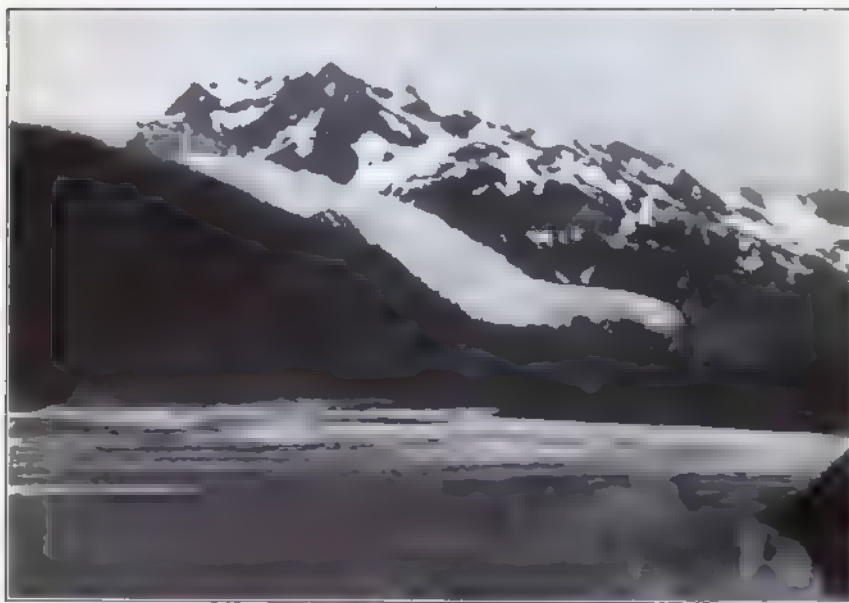
B. SOUTH PART OF FRONT OF BAINBRIDGE GLACIER.

From point B, figure 7. August 3, 1908. Photograph G 43.



A. ICE FRONT, PUSH MORaine, AND DEAD TREES AT NORTH SIDE OF FRONT OF BAINBRIDGE GLACIER.

August 3, 1908. Photograph G 41.



B. PUGET GLACIER

From point A, figure 8. July 11, 1909. Photograph G 117

north encroaches upon a spruce forest, many of whose trees have been killed by being partly buried in glacial outwash (Pl. XXX, A). Between the south part of the front (Pl. XXIX, B) and the forest is a small irregular bare zone of rock.



FIGURE 7.—Map of front part of Bainbridge Glacier August 3, 1908. Occupied points indicated by circles; intersected points by crosses.

The photographs here reproduced (Pls. XXIX, A and B, and XXX, A) mark the position of the front of the Bainbridge Glacier on August 3, 1908, and will be of service in determining future advance or retreat. In 1908 the ice was practically if not absolutely at its limit of maximum advance since the growth of the present forest.

Photographs of Bainbridge Glacier.

G 39. Bainbridge Glacier from east side of Port Bainbridge and just north of north entrance to Hogg Bay. August 2, 1908.

G 40. Here reproduced as Plate XXIX, *A*. Front of Bainbridge Glacier from point A, Figure 7. August 3, 1908. Point A is on the top of the most southerly reef at the north entrance to the shallow bay in which is the Bainbridge Glacier; this reef is covered by the ordinary high tide.

G 41. Here reproduced as Plate XXX, *A*. North part of front of Bainbridge Glacier, showing push moraine, overturned trees, and dead forest. August 3, 1908.

G 42. Detail of front of Bainbridge Glacier. August 3, 1908.

G 43. Here reproduced as Plate XXIX, *B*. South part of front of Bainbridge Glacier from point B, Figure 7. August 3, 1908. Point B is at low-tide line on the south bank of one of the larger glacial streams.

GLACIERS OF THE SOUTHERN SHORE OF KENAI PENINSULA.

CAPE PUGET TO CAPE RESURRECTION.

Between Prince William Sound and Resurrection Bay, or more strictly between Capes Puget and Resurrection, there are at least four marked indentations of the shore line having valleys opening into them. Each of these valleys contains a glacier. From east to west these glaciers are the Puget, the Excelsior, an unnamed glacier, and the Ellsworth. This coast lacks good harbors that are not exposed to the southerly winds and except for Day Harbor has been seldom visited and not carefully mapped. Our delineation of this shore (see southwest corner of Pl. I and east edge of Pl. II, in pocket; also figs. 8 and 9) shows more details than other maps but can not be regarded as accurate.

PUGET GLACIER.

The Puget Glacier, to which we apply the name of the adjacent cape and bay, ends about a mile and a quarter from the head of Puget Bay. This glacier is shown on Tebenkof's map ¹ (1852) and probably also on Vancouver's map, though it is omitted from recent United States Coast and Geodetic Survey charts (Nos. 8502 and 8550). We visited the head of Puget Bay on July 11, 1909, at which time the accompanying sketch map (fig. 8) was made and the glacier was photographed (Pl. XXX, *B*).

The surface of the upper part of the Puget Glacier is smooth, but about a mile and half above its lower end the glacier narrows and for half a mile its surface is steep and much crevassed. It then widens and becomes smooth again but farther down passes over a cliff, on the top of which the western side of the glacier ends in an ice wall estimated to be 200 feet in height. The blocks of ice which fall over the cliff from this wall probably do not consolidate, although this was not conclusively shown by our observations. The eastern part of the ice stream comes over this cliff in a much crevassed condition and then

¹ Davidson, George, *op. cit.*, p. 20, map 5.

becomes smoother and deploys toward its end. Beyond the end of the glacier is a bare zone of considerable extent, between which and the sea is a mature forest. The bare zone appears to have been occupied recently by the glacier. Davidson¹ states that the glacier ended half a mile from the shore; this distance was probably taken from the older maps (Tebenkof's or Vancouver's), for evidently it was not carefully measured. We did not go nearer the glacier than point A, figure 8.

EXCELSIOR GLACIER.

The name Excelsior is in use locally for this glacier; we do not know when the name was applied and have heard of no other name being used for this ice stream, which is shown on the earlier maps.¹ We passed within 2 miles of the glacier on July 11, 1909. Its front appears to be within half a mile of the sea. On the east is a very wide bare zone between the ice and the forest, and on the west there is also a bare zone, but this is not so clearly seen. The glacier ends on a low gravel flat, the central part of which is bare of vegetation. From the appearance of these bare zones it seems that the Excelsior Glacier has been considerably larger within a few years, and its front may have reached the sea very recently.

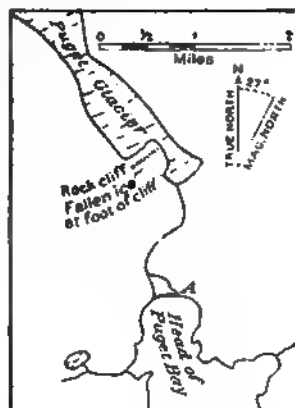


FIGURE 8. Sketch map of Puget Glacier and head of Puget Bay July 11, 1909.

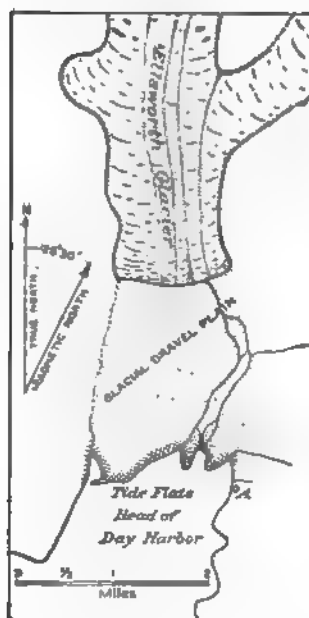


FIGURE 9. Sketch map of Ellsworth Glacier and head of Day Harbor July 12, 1909.

ELLSWORTH GLACIER.

The Ellsworth Glacier is situated at the head of Day Harbor, the first bay east of Resurrection Bay. This glacier is not mentioned by Davidson and evidently did not appear on the maps of Tebenkof or Vancouver. It is shown as reaching tide-water on United States Coast and Geodetic Survey chart 8502 (1907). We visited the head of Day Harbor on July 12, 1909, at which time the accompanying sketch map (fig. 9) of the glacier was made, mainly from point A. The name Ellsworth Glacier is in use at Seward, the glacier being named after H. E. Ellsworth of that place.

¹ Davidson, George, op. cit., p. 20, map 6.

The Ellsworth Glacier is an ice stream of considerable length and low slope. It ends about a mile and three-quarters from tidewater. The glacier carries four well-marked medial moraines, and the eastern part of its front is covered with much *débris*. Two feeders join it from the east. About opposite the upper feeder is a nunatak, and a little south of this feeder and farther west is another nunatak of small size, both of which rise only a little above the ice surface. On the west side of the end of the glacier is a bare zone perhaps 200 feet in height (Pl. XXXI, A). On the east side of the end is a morainic deposit, also bare of vegetation, and there are some morainic hillocks in front of the glacier. Part of the outwash plain is covered with vegetation. We did not visit the front of the glacier and therefore have no information as to recent retreat or advance, except for the bare zone noted above. It is very improbable that this glacier has reached tidewater within historic time.

West of the head of Day Harbor are two other north-south valleys. The eastern one contains two small glaciers some 8 or 10 miles from the sea, and on the western side of the western valley is another small glacier about 4 miles from the sea. In the mountains west of the head of Day Harbor are several cirques, one of which contains the small glacier just noted. Three other cirques have moraines across their fronts and possibly may contain small glaciers.

Photographs of glaciers between Capes Puget and Resurrection.

G 117. Here reproduced as Plate XXX, B. Puget Glacier from point A, figure 8. July 11, 1909. Point A is near the east end of the beach at the head of Puget Bay.

G 118. West side of front of Excelsior Glacier from boat. July 11, 1909.

G 119. East side of front of Excelsior Glacier from boat. July 11, 1909.

G 120. Ellsworth Glacier from boat. July 12, 1909.

G 121. Here reproduced as Plate XXXI, A. Ellsworth Glacier from point A, figure 9. July 12, 1909. Point A is the top of a drift hill about 60 feet above sea level, undercut on the north side, at the northeast corner of Day Harbor. The summit of the hill is forested, and the station is at the edge of the forest and at the top of the steep northerly slope.

G 215. Hanging valley and cirque possibly containing a glacier, at west side of head of Day Harbor. July 12, 1909.

RESURRECTION BAY.

Resurrection Bay is the most northerly extending indentation of the coast line of the Gulf of Alaska between Prince William Sound and Cook Inlet. The high mountains east of this bay carry several small glaciers, which end far above sea level, and on the west side of the bay is the Bear Glacier, the largest ice stream to reach the sea on the Kenai Peninsula.

THUMB COVE GLACIERS.

On August 21 and 22, 1908, we made a short trip to Thumb Cove (locally known as Porcupine Bay), and in visiting the prospects in

this vicinity made a sketch (fig. 10) and took a few notes on the glaciers near this little bay. Although these glaciers, when viewed from the bay, seem to be clinging to the mountains as hanging glaciers, a visit to them reveals the fact that they occupy well-defined valleys. The Spoon and Prospect Glaciers especially occupy well-developed cirques whose walls are in places nearly a thousand feet sheer. The Porcupine Glacier was not visited, but its front could be very well seen from tidewater.

The Prospect Glacier was named from the fact that S. E. Likes has done considerable prospecting along the back cirque wall. The front of the glacier is breaking over a small rock cliff. The Spoon Glacier was so named on account of its smooth, glassy, round front, which reminds one approaching from below of the inverted end of a huge spoon. The Porcupine Glacier bears the local name of the bay.

The bare areas about the fronts of all these glaciers indicated in 1908 a minimum recorded extent of the ice. Between the Prospect and Spoon glaciers is an abandoned medial moraine. It is about 80 feet high in the highest parts, its top is sharp, and its sides are very steep, for they have not yet adjusted themselves to an angle less than that of repose for the material of the moraine. Boulders of prodigious size are common. The largest one seen was estimated as equal to a 20-foot cube. The condition of the vegetation on the moraine indicates that several decades have passed since these glaciers coalesced.

Just north of the Prospect Glacier is what appears to be a small ice cap covering the top and upper part of the western slope of a mountain more than 4,000 feet in height.

GODWIN GLACIER.

The Godwin Glacier is on the east side of Resurrection Bay directly east of Seward, and is the source of Godwin River. The glacier ends about 3 miles from the bay at an altitude of approximately 1,000 feet. The end of the glacier is forked, and in front of it, as seen from the bay, is a bare zone about a quarter of a mile wide. Next to this is another zone of similar width covered with bushes, after which comes a forest extending to sea level.

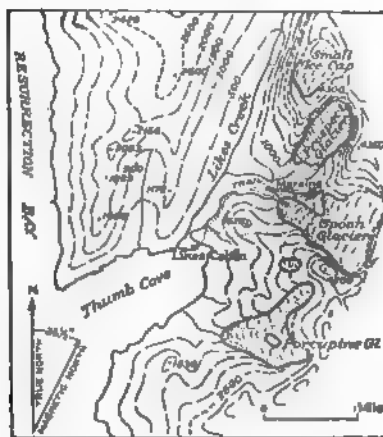


FIGURE 10.—Sketch map of Thumb Cove glaciers, Resurrection Bay, August 21, 1908. Crosses indicate copper prospects; shore line and elevations from United States Coast and Geodetic Survey; contour interval 500 feet.

BEAR GLACIER.

The Bear Glacier ends on a gravel flat on the west side of Resurrection Bay 12 miles south of Seward. The name Bear Glacier is in use at Seward. Our visit to this glacier was made on July 20 and 21, 1909. No accurate information concerning the glacier, except its existence and the fact that it reaches sea level, was available before the publication of chart No. 8538 of the United States Coast and



FIGURE 11.—Map of front part of Bear Glacier July 20 and 21, 1909. Occupied points indicated by circles; arrows show directions in which photographs were taken; elevations from United States Coast and Geodetic Survey chart No. 8538; contour interval, 200 feet.

Geodetic Survey. This map shows that the front of the glacier was in essentially the same position in 1905 as it was in 1909.

The Bear Glacier has a comparatively low slope and carries two large medial moraines (fig. 11). The gravel flat on which the glacier rests is partly covered by the highest tides, and apparently a combination of highest tide and strong southerly wind brings waves over the greater part of it. Along the center of the ice front high tide reaches the glacier. On the east side of the flat is a gravel terrace



A. ELLSWORTH GLACIER

From point A, figure 9. July 12, 1909. Photograph G 121.

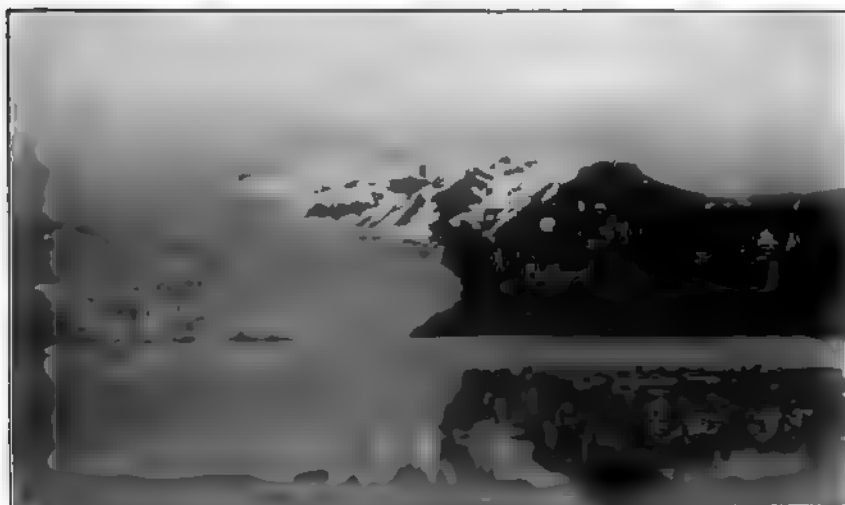


B. EAST PART OF FRONT OF BEAR GLACIER

From point B, figure 11. July 20, 1909. Photograph G 123.



.1. WEST PART OF FRONT OF BEAR GLACIER,
From point C, figure 11. July 21, 1909. Photograph G 124.



.2. NORTH PART OF AIALIK GLACIER,
From point A, Plate XXXIII. July 23, 1909. Photograph G 221

(Pl. XXXI, *B*) covered with grass and a few bushes; the terrace at its south end is at high-tide level and rises about 30 feet in going northward a mile. A small remnant of apparently the same terrace persists on the western part of the glacial flat. The top of the terrace probably represents the surface of the outwash plain as it was when the glacial front stood farther back than at present.

Northeast of the glacial front is a bare rock face about 200 feet high, evidently recently glaciated, and south of this is a rocky island in the glacial flat. The northwestern side of the island is bare of timber, but the southeastern side is wooded. West of the glacier front is a bare zone about 200 feet high (Pl. XXXII, *A*), which extends a quarter of a mile beyond the ice front. This bare zone has been invaded recently by talus cones, and its upper side is not sharply marked. The glacier front, therefore, has been perhaps a quarter of a mile in advance of its present position in comparatively recent years, but has not been farther advanced than that distance since the growth of the present forest.

The probable fluctuations of the Bear Glacier since the growth of the present forest may be recorded as: (1) A maximum advance to and into the forest, perhaps 25 or more years ago; (2) a retreat of an unknown distance, during which an outwash plain (now represented by remnants of a terrace) was constructed at a higher level than the present plain; and (3) an advance to the present position, which is perhaps a quarter of a mile short of the maximum mentioned above.

Photographs of glaciers of Resurrection Bay.

G 63. View northeastward into Thumb Cove from boat, showing small ice cap on left, névé field of Spoon Glacier on right and Prospect Glacier in center, with surrounding peaks. August 21, 1908.

G 64. Same as G 63; a closer view. August 21, 1908.

G 65. Porcupine Glacier and surrounding mountains from boat near head of Thumb Cove. August 21, 1908.

G 122. East part of front of Bear Glacier from point A, figure 11. July 20, 1909.

G 123. Here reproduced as Plate XXXI, *B*. East part of front of Bear Glacier from point B, figure 11. July 20, 1909.

G 124. Here reproduced as Plate XXXII, *A*. West part of front of Bear Glacier from point C, figure 11. July 21, 1909.

G 125. Bear Glacier from boat. July 21, 1909.

AIALIK BAY.

GENERAL FEATURES.

Aialik Bay is the deep bay just west of Resurrection Bay. Both the point between these two bays and the shores of Aialik Bay are very irregular, being indented by many approximately semicircular small bays and coves, which represent old glacial cirques partly or completely drowned. (See Pl. XXXIII.) The drowning is most pronounced at the south end of the bay, and the cirque floors rise gradually until at the north end they lie above sea level.

On the eastern shore of the upper half of Aialik Bay are four small glaciers. On the western shore of the bay are other glaciers high up in the mountains, and three large glaciers reach tidewater. (See Pl. XXXIII.) These three ice streams, as well as the Bear Glacier, come from an immense snow field lying northwest of Aialik Bay. The depth and extent of this snow field are unknown, but it is one of the largest, if not the largest, on the Kenai Peninsula. Glaciers from the western side of this snow field drain into Tustumena Lake and probably others into Skilak Lake.¹

AIALIK GLACIER.

The Aialik Glacier reaches tidewater at the west side of the extreme head of Aialik Bay, whence the name here applied. This glacier is not mentioned by Davidson,² and so probably was not shown on Vancouver's and Tebenkof's maps. It is shown as reaching tidewater on chart No. 8502 of the United States Coast and Geodetic Survey (1907). We visited the Aialik Glacier on July 23, 1909, and most of our observations were made from the top of Squab Island, a mile east of the southern part of the front of the glacier and 100 feet above sea level (point A, Pl. XXXIII).

The glacial front is a cliff, estimated to be 200 feet high, from which ice is being discharged rapidly. There is no medial moraine on the Aialik Glacier, and the lateral moraines, especially the one on the northeast side, are not large. At the center of the front a small mass of rock has just been uncovered by the ice, and another small mass appears about a third of the way from the center to the north end of the front (Pl. XXXII, *B*). On each side of the glacier is a marked bare zone, and in the bare zone on the south side is a lateral moraine (Pl. XXXIV, *A*). When the ice extended over this bare zone, possibly 10 years ago, the front was about a quarter of a mile in advance of its present position. Much more advanced positions of the Aialik Glacier, occupied several centuries ago, are indicated by shoals, caused by morainic accumulations, stretching across the head of Aialik Bay opposite and a mile north of the front of the Pederson Glacier.

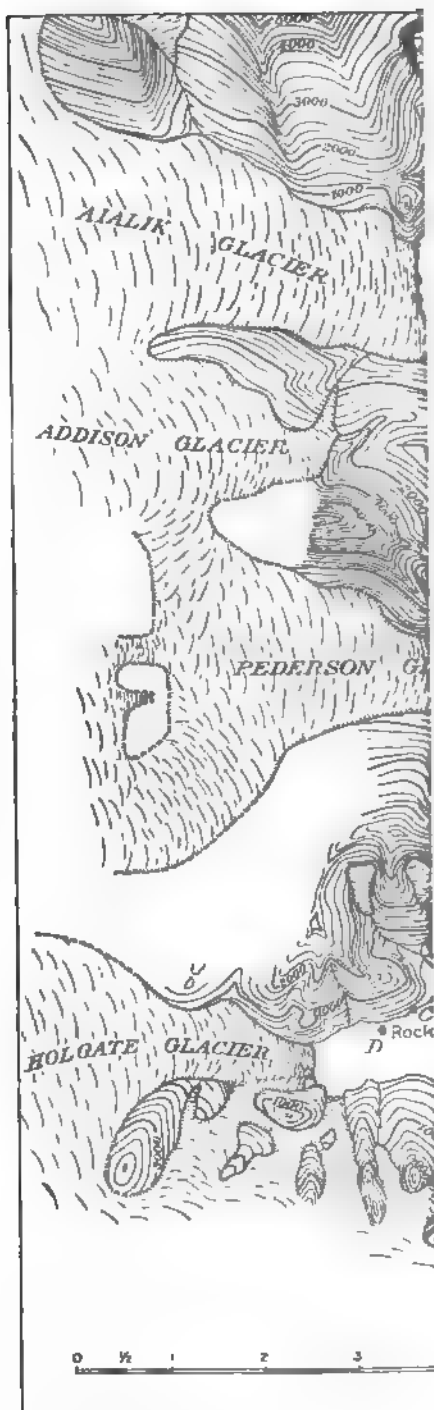
PEDERSON GLACIER.

The Pederson Glacier ends 4 miles south of the Aialik Glacier. Davidson² states that the Pederson Glacier is shown by Tebenkof (1852), and that it ends half a mile from the sea. We visited this glacier on July 23, 1909.

Toward its end the Pederson Glacier is smooth; it deploys upon a glacial flat, and the center of its front is reached by high tide (Pl.

¹ Recently the extent of this great snow field, especially to the west and north, has been determined by R. H. Sargent, of the United States Geological Survey.

² *Op. cit.*, p. 19, map 4.



MAP OF UG
July 22-24, 1909. Occupied points ind



1. SOUTH PART OF FRONT OF AIALIK GLACIER.
From point A, Plate XXXIII. July 23, 1909. Photograph G 220.

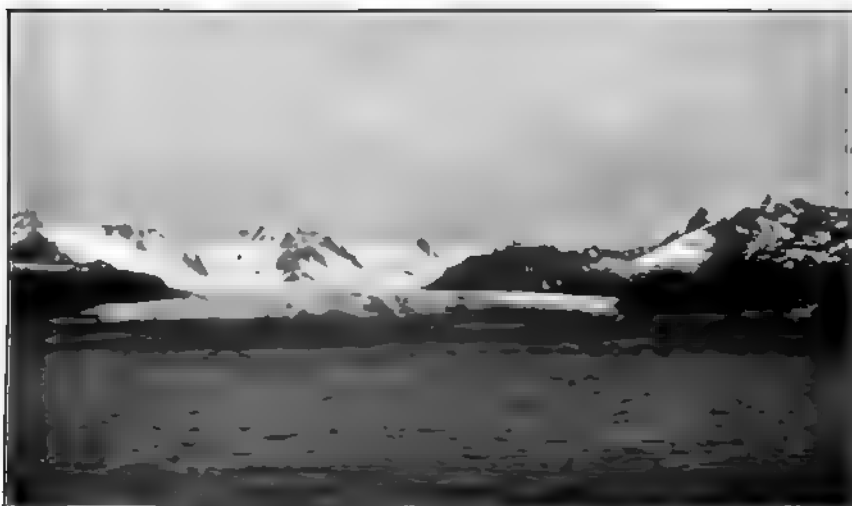


2. NORTH PART OF FRONT OF PEDERSON GLACIER.
From point B, Plate XXXIII. July 23, 1909. Photograph G 130.



A. HOLGATE GLACIER

From point C, Plate XXXIII. July 24, 1909. Photograph G 132.



B. NORTHWESTERN GLACIER

From point D, northeast of the north end of the granite is and 5 miles long at the east end of Harris Bay. July 27, 1909. Photograph G 138

XXXIII). The northern part of the front forms a perpendicular cliff of ice perhaps 100 feet high. This glacier has no medial moraine and has a well-marked bare zone on each side of the front. On the north side this zone is approximately 200 feet high where it touches the ice, and it extends a third of a mile east from the present front of the glacier (Pl. XXXIV, *B*). Along much of the front, a quarter to a third of a mile from the ice, are remnants of a low moraine, which has now been nearly cut away by the waves. On this moraine are herbaceous plants and some alders about 2 feet high. The moraine was probably deposited at the time when the glacier advanced to the edge of the bare zone mentioned above. This advance may have been made 15 years ago and apparently was the maximum advance of the glacier since the advent of the present forest. The earlier recorded position of the ice front mentioned by Davidson was probably close to its position in 1909.

HOLGATE GLACIER.

The Holgate Glacier lies at the head of Holgate Bay, the main westerly branch of Aialik Bay. This glacier is mentioned by Davidson as nearly reaching the beach and is shown on Tebenkof's map (1852).¹ We examined this glacier from points C and D, Plate XXXIII, on July 24, 1909.

The Holgate Glacier reaches tidewater in two streams separated by a small mass of rock, which not many years ago was a nunatak in this glacier. (See Pls. XXXIII and XXXV, *A*.) The northern and larger stream is discharging rapidly, but the discharge from the southern stream is small. Near the south side of the larger stream is a small medial moraine, but the glacier as a whole is free from medial moraines. The same statement can be made concerning the other glaciers on the west side of Aialik Bay. They all come from an extensive snow field that has few bare peaks rising above its surface.

About three-fourths of a mile east of the front of the northern stream of the Holgate Glacier is a rounded reef, recently glaciated and now covered by the highest tides. (See point D, Pls. XXXIII and XXXV, *A*.) There are no trees on the sides of Holgate Bay within 1½ miles of its head, and beyond this the forest is sparse. There are no bushes and very few herbaceous plants close to sea level from the glacier to a point a quarter of a mile east of the reef mentioned above. The rock mass between the two parts of the glacial front has bushes only on its upper half on the front and on its upper fourth on the sides. (Pl. XXXV, *A*.) In very recent years, then, possibly within the twentieth century, the front of the Holgate Glacier was about a mile in advance of its position in 1909.

¹ Davidson, George, loc. cit.

On the southwestern side of Holgate Bay several ice tongues descend the mountain sides but do not reach within a few hundred feet of sea level. Most of these glaciers lie in shallow valleys, and all come apparently from the same part of the great snow field that feeds the Holgate Glacier.

Photographs of glaciers of Aialik Bay.

G 127. Pederson Glacier from boat. July 22, 1909.

G 128. South part of front of Aialik Glacier from point A, Plate XXXIII. July 23, 1909. Point A is the top of a rocky islet a mile east of the glacier.

G 129. North part of front of Aialik Glacier from point A, Plate XXXIII. July 23, 1909.

G 130. Here reproduced as Plate XXXIV, *B*. North part of front of Pederson Glacier from point B, Plate XXXIII. July 23, 1909.

G 131. South side of front of Pederson Glacier from point B, Plate XXXIII. July 23, 1909.

G 132. Here reproduced as Plate XXXV, *A*. Holgate Glacier from point C, Plate XXXIII. July 24, 1909. Point C is on a shingle beach on the north side of Holgate Bay, about 1.2 miles from the glacier.

G 133. North part of Holgate Glacier from point D, Plate XXXIII. July 24, 1909. Point D is on a large rock reef, which is apparently covered by the highest tides, and is shown in photograph G 132 (Pl. XXXV, *A*).

G 134. South part of Holgate Glacier from point D, Plate XXXIII. July 24, 1909.

G 135. Glaciers on south side of Holgate Bay from boat. July 24, 1909.

G 220. Here reproduced as Plate XXXIV, *A*. South part of front of Aialik Glacier from point A, Plate XXXIII. July 23, 1909.

G 221. Here reproduced as Plate XXXII, *B*. North part of front of Aialik Glacier from point A, Plate XXXIII. July 23, 1909.

G 222. Glaciers on south side of Holgate Bay from boat. July 24, 1909.

G 223. Holgate Glacier from point C, Plate XXXIII. July 24, 1909.

G 224. South part of Holgate Glacier from point D, Plate XXXIII. July 24, 1909.

G 225. North part of Holgate Glacier from point D, Plate XXXIII. July 24, 1909.

NORTHWESTERN GLACIER.

The Northwestern Glacier (fig. 12) reaches the ocean at the head of Harris Bay, the second large bay southwest of Resurrection Bay. This glacier is one of the largest ice streams of the Kenai Peninsula and is in full view from the open ocean, forming, with its surrounding lofty peaks, the most striking scenic feature of the southern shore of the Kenai Peninsula. The Northwestern Glacier, which we named after Northwestern University, is shown by Tebenkof¹ as reaching almost to the sea. We visited this glacier on July 26 and 27, 1909, and examined it from points 1 to 5 miles distant and also from a boat less than a mile from the glacier front.

The Northwestern Glacier descends from a large ice field northwest of Harris Bay. Eight or 10 miles from the water several peaks stand out above the edge of this ice field, and from the vicinity of these peaks ice streams descend rapidly to a wide, low valley, which

¹ Davidson, George, loc. cit.



1. EAST PART OF FRONT OF NORTHWESTERN GLACIER.

From point A, figure 12. July 26, 1909. Photograph G 137.



2. WEST PART OF FRONT OF NORTHWESTERN GLACIER.

From boat July 27, 1909. Photograph G 140.

the main glacier follows to the sea. The glacier shows on its surface a number of well-marked medial moraines, six of which come down to its tidewater front; at least two others end in the hills on the north (Pl. XXXV, *B*). The peaks just mentioned and the medial moraines coming from them are of reddish granite, and in consequence the surface of the glacier is striped with bands of a buff color. The west quarter of the front of the glacier forms a steep cliff and is discharging rapidly. The eastern half of the front lies on a gravel flat, the eastern part of which is not covered by high tide. On each side of the front there is a bare zone between the glacier and the forest (Pl. XXXVI). This zone extends a quarter of a mile beyond the front of the glacier and is estimated to reach 150 feet in height above the surface of the glacier near its front.

The front of the Northwestern Glacier was in 1909 about a quarter of a mile back of its position of maximum advance since the growth of the present forest. This maximum position was occupied perhaps 10 to 15 years ago.

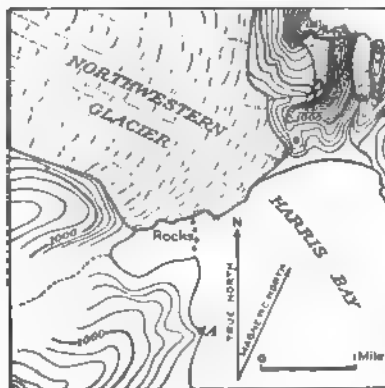


FIGURE 12.—Sketch map of front part of Northwestern Glacier July 23, 1909. Occupied points indicated by circles, intersected points by crosses. Contour interval, 200 feet.

Photographs of Northwestern Glacier.

G 136. Northwestern Glacier from boat. July 26, 1909.

G 137. Here reproduced as Plate XXXVI, *A*. Eastern part of front of Northwestern Glacier from point A, figure 12. July 26, 1909. Point A is at the base of the rocky spit connecting a small island with the west shore of Harris Bay, about 1.2 miles south of the front of the Northwestern Glacier.

G 138. Here reproduced as Plate XXXV, *B*. Northwestern Glacier from end of point on south side of the second large bay from the glacier on the east side of Harris Bay. This point is just northeast of the north end of the granite island 5 miles long at the eastern entrance to Harris Bay. July 27, 1909.

G 139. Same position as G 138; the camera was turned a little more to the left. July 27, 1909.

G 140. Here reproduced as Plate XXXVI, *B*. Western part of front of Northwestern Glacier from boat. July 27, 1909.

G 226. Northwestern Glacier. July 26, 1909.

TWO ARM BAY.

Two Arm Bay, thus called locally from its form, lies 18 miles west of Chiswell Islands and 12 miles northeast of Pye Islands. (See Pl. II, in pocket.) Tebenkof, as quoted by Davidson,¹ in-

¹ Davidson, George, loc. cit.

dicates a glacier coming close to but not reaching tidewater at the head of each arm of this bay. The same glaciers, the western one coming to sea level, are shown on United States Coast and Geodetic Survey chart No. 8502 (1907). We visited the heads of both arms of this bay in July, 1909. There is no glacier to be seen on the western arm, and we noted no evidence of the presence of one in historic times; neither do the streams entering the bay, as far as we saw, carry glacial silt. About the head of the eastern arm of this bay, however, are at least four small glaciers whose waters reach the bay. These ice streams end about 1,000 feet above sea level, and one of them evidently comes from the same great ice field from which the Northwestern and McCarty glaciers flow. Our recollection is that there is a mature forest separating all these glaciers from the sea, so they have not reached nearly to tidewater in historic times.

NUKA BAY.

GENERAL FEATURES.

Nuka Bay is the large inlet lying just west and northwest of the Pye Islands. It has several arms or branches. At the head of the eastern arm is the McCarty Glacier, the most westerly to reach tidewater on the southern shore of the Kenai Peninsula. The Split Glacier ends about 2 miles from the head of the northern arm. On the southwest shore of the northwest arm are at least four glaciers, but none of them end near sea level. The western arm (Yalik Bay) has no glaciers draining into it. On the western side of Nuka Bay south of Yalik Bay are two larger glaciers, Yalik and Petrof, and several smaller ones which do not reach the sea but whose waters drain into Nuka Island Passage. The information here given concerning the glaciers of Nuka Bay was obtained between July 30 and August 8, 1909.

M'CARTY GLACIER.

The McCarty Glacier reaches the sea at the head of the northeastern arm of Nuka Bay (fig. 13). The glacier was named by residents of the locality after William McCarty, of Seward. It has a prominent medial moraine in its western half, which stands up above the ice surface as a ridge. The front of the glacier deploys in semicircular form on a gravel flat, which is mainly above sea level. At the center of its front, however, the glacier reaches tidewater and in places presents a steep wall about 200 feet high. From this wall blocks of ice fall into the water, which is so shallow that the larger icebergs do not float away.

East of the front of the McCarty Glacier is a broad pitted plain, and nearer the ice are morainic ridges which mark an advance of



A. EAST PART.

Photograph G 143.



B. CENTRAL PART

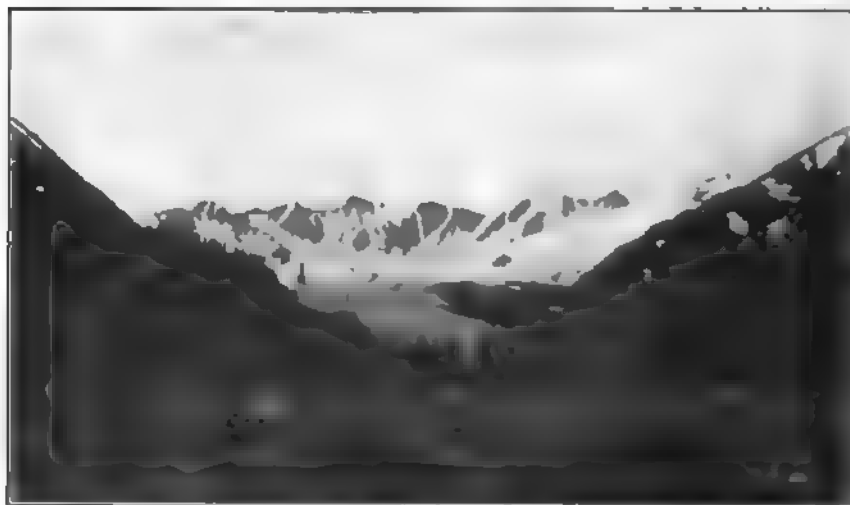
Photograph G 144

FRONT OF McCARTY GLACIER.
From point A, figure 13. July 30, 1909.



A. WEST SIDE OF McCARTY GLACIER.

From point B, figure 13. July 30, 1909. Photograph G 228.



B. SPLIT GLACIER

From point G, figure 15. August 2, 1909. Photograph G 233.

the ice some years ago. Between the glacier and Delight Lake these morainic ridges reach a height of 60 feet. South of this lake a rock ridge extends westward within about a quarter of a mile of the glacier. This ridge is shown on the right side of Plate XXXVII, A. The end of the ridge is of bare rock and has been glaciated up to a height of 250 feet, at which elevation the ice invaded a mature forest and killed many of the trees, which are now without bark and most of which are lying on the ground. Standing among the dead trees are live spruces, the largest of which are 12 feet high and 6 inches in diameter. The advance of the ice that destroyed the large trees and constructed the morainic ridges just mentioned occurred perhaps 50 years ago and is the extreme advance of the eastern part of the glacier since the growth of the present forest.

On the west side of the glacial front is a gravel plain with two lines of low morainic ridges, one near the outer edge of the plain and one within about a quarter of a mile of the ice. These morainic accumulations were probably synchronous, respectively, with the old and young lateral mo-

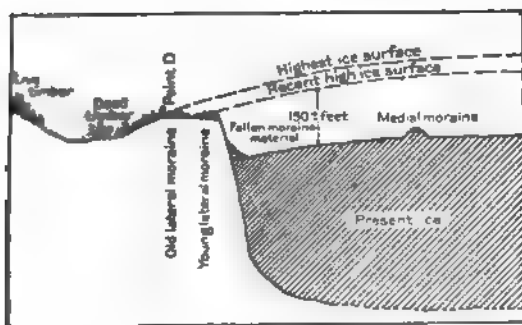


FIGURE 14.—Diagrammatic cross section of west side of McCarty Glacier, taken east and west through point D of figure 13. Vertical scale greatly exaggerated.

the top of this ridge and just west of the ice (point D, fig. 13) an excellent view of the glacier and its environs is obtained. Here are two lateral moraines now beyond the edge of the ice. The older and outer of these moraines is not very well defined and ranges from

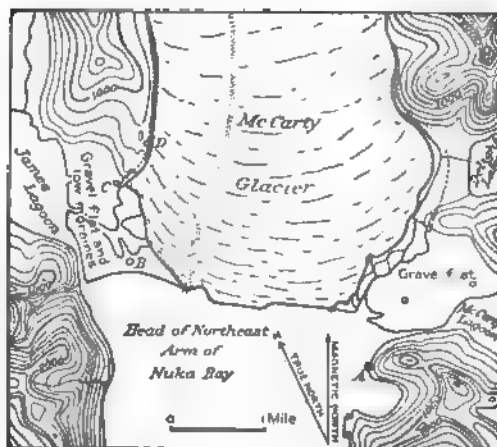


FIGURE 13.—Map of front part of McCarty Glacier July 30, 1909. Occupied points indicated by circles, intersected points by crosses. Dotted lines at sides of glacier indicate limits of bare zones. Contour interval, 200 feet.

and one within about a quarter of a mile of the ice. These morainic accumulations were probably synchronous, respectively, with the old and young lateral moraines shown in figure 14.

The extreme western side of the McCarty Glacier falls abruptly over the point of a rock ridge some 350 feet high. (See Pl. XXXVIII, A.) From

a few feet to 12 feet in height. Moss and young spruce trees cover most of its surface, and in it are many fragments of tree trunks and stumps. Just outside this moraine on the west is a forest practically all whose trees near the ice were killed at the time, apparently, at which the moraine was formed (fig. 14). These trees are in about the same stage of decay as the fragments of wood in the moraine and are all in a more advanced stage than the trees at any other locality described in this report where a forest has been invaded by the ice, except those of the forest destroyed by the maximum

advance of the eastern part of the Columbia Glacier. The advance that killed these trees was the maximum of the western part of the McCarty Glacier since the growth of the present forest and probably occurred at the time of the maximum advance shown on the eastern side of the same glacier.

East of the lateral moraine just described is a similar but much younger one. On this there is little moss, but many young spruce trees 1 to 12 inches high.

SPLIT GLACIER.

The Split Glacier ends in the upper part of a steeply graded, gravel-filled valley at the head of the north arm of Nuka Bay (Pl. XXXVIII, B). The front of the glacier is bifurcate, because of a rock ridge near its center. About the edge of the ice is a bare zone, whose limits are shown by the outer dotted line on the map (fig. 15). On the central ridge and the hills on the side of the valley this bare zone is sharply marked, but in the center of the valley it merges into the bare gravel floor.

Within this zone is a smaller one, indicated by the inner dotted line on the map, marking the limit of a more recent advance of the ice.

The distance from the forest on the eastern part of the central ridge north to the ice is a little over a fourth of a mile. As one walks from the forest-covered part of this ridge northward toward the glacier he passes at first through a dense growth of alders, grass, and moss, which gradually becomes smaller and less dense as the ice is approached, thus indicating a very gradual retreat of the glacier from its maximum advance since the advent of the present forest.



FIGURE 15.—Map of front part of Split Glacier August 2, 1909. Occupied points indicated by circles, intersected points by crosses. Arrows indicate directions in which photographs were taken. Contour interval, 200 and 100 feet, the smaller interval being used in the immediate vicinity of the glacier front. Dotted lines about front of glacier indicate limits of recent advances.

The narrow tongue of ice projecting from the eastern part of the glacial front is a *débris*-covered remnant of the ice of the most recent advance. The low area between point F, shown in figure 15, and the front of the western lobe of the glacier is occupied by gravel-covered ice, which seems to be floating on water, and parts of the

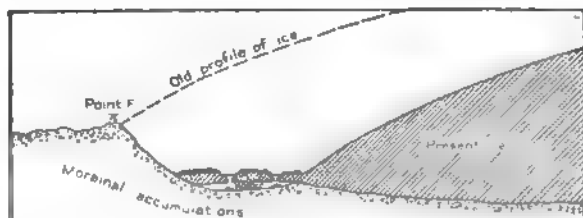


FIGURE 16.—Diagrammatic cross section of front edge of Split Glacier.

ice have caved in because of the weight of the gravel. (See Pl. XXIV, B, and fig. 16.)

The Split Glacier with its surrounding mountains forms a scene of quiet color and beauty not excelled by any among the glaciers of Prince William Sound and the southern part of the Kenai Peninsula. The ice front is smooth and easy of access, and the glacier would probably afford an easy route for exploration from Nuka Bay across to the head of Kachemak Bay of Cook Inlet.

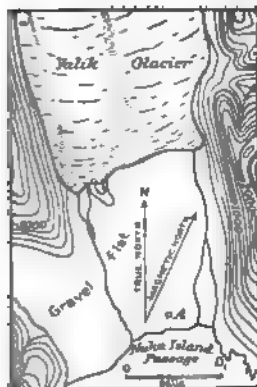


FIGURE 17.—Sketch map of front part of Yalik Glacier August 7, 1909. Contour interval, 200 feet.

YALIK GLACIER.

The Yalik Glacier ends on a steep gravel flat about 2 miles north of the northwestern side of Nuka Island Passage (fig. 17). The glacier was named from the small settlement of Yalik, which formerly existed on the southern of the two western arms of Nuka Bay. This glacier has two prominent medial moraines, which spread toward the end of the ice, so that about half of the frontal edge of the glacier is *débris*-covered. There is a bare zone along the glacier front, and at the edge of this zone is a forest that was invaded by the ice some years ago. Part of the gravel plain in front of the glacier is forested, as is a rock ridge rising out of the plain near the western part of the glacier front. In places, especially toward the eastern side of the plain, the forest has been partly buried and many trees have been killed by outwash from the glacier (Pl. XXXIX, A). This probably occurred at the time of the advance marked by the limit of the bare zone along the ice front.

PETROF GLACIER.

The Petrof Glacier ends on a gravel plain west of Nuka Island Passage and about a mile from the sea (fig. 18). This glacier was named after Ivan Petrof, who was special agent for Alaska of the Tenth Census (1880).

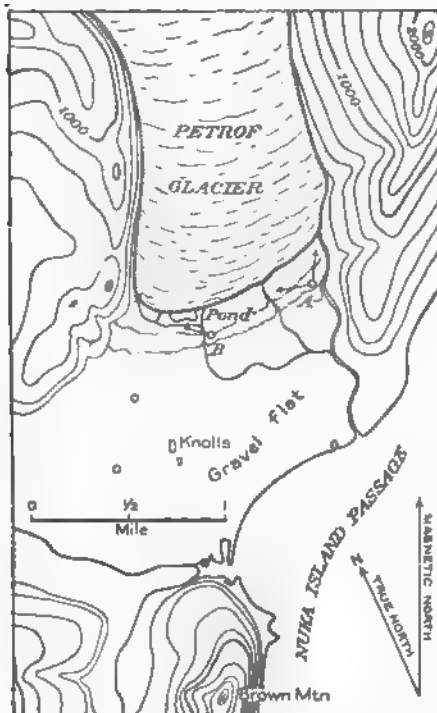


FIGURE 18.—Sketch map of front part of Petrof Glacier August 8, 1909. Occupied points indicated by circles, intersected points by crosses. Arrows indicate directions in which photographs were taken; hachures indicate small terminal moraines. Contour interval, 200 feet.

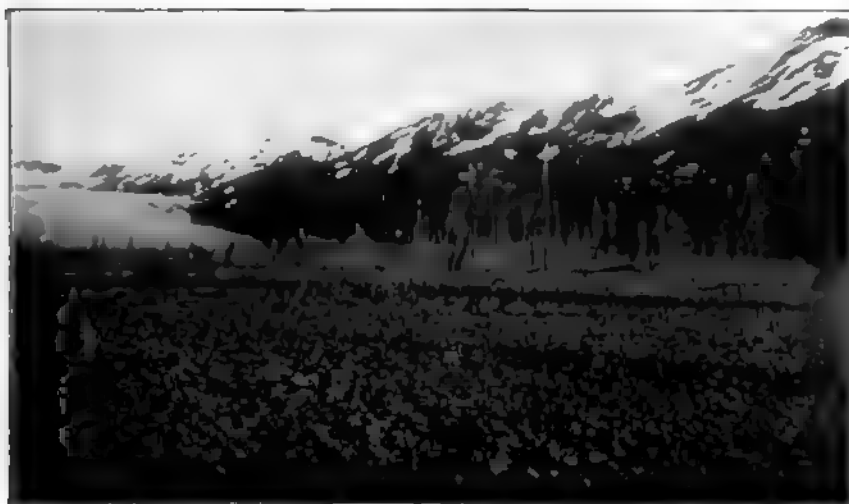
The Petrof Glacier has no medial moraines; it has no lateral moraine along its eastern side and only a small one along its western side. A bare zone extending along both the east and the west parts of the ice front has been encroached upon by small vegetation (Pls. XXXIX, B, and XL, A). Two small terminal moraines cross the upper end of the gravel flat in front of the glacier.

In front of the Petrof Glacier are small ridges, 1 to 5 feet wide and 6 to 18 inches high. Some are 200 feet in length (Pl. XL, B). They run out from the ice front and in places cross small push moraines. These ridges are connected with radial fissures in the thin edge of the ice and are formed by debris falling into these fissures from the melting front of the ice. The fissures

are widened by the melting, and their sides become sloping; thus the bottom of each one receives most of the drift which lies on the surface of the ice in a space two to four times the width of the ground uncovered by the fissure. As the ice front retreats the debris deposited in the fissures stands up as small ridges.

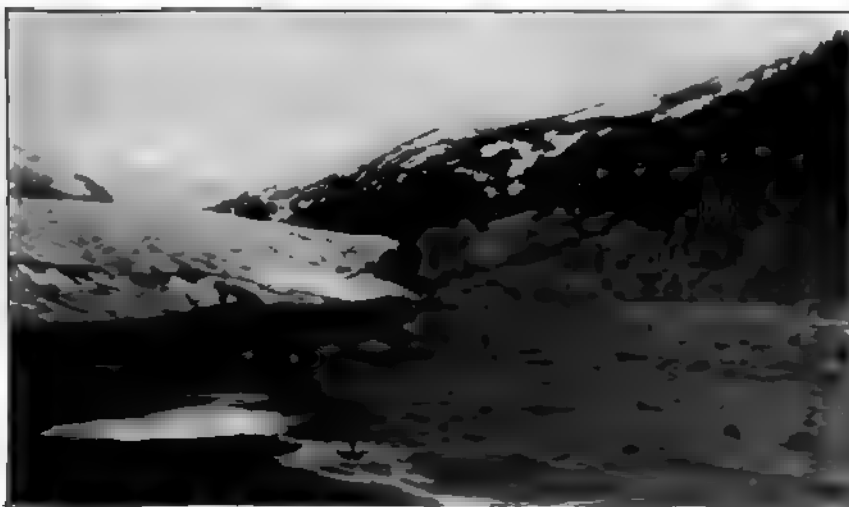
Photographs of glaciers of Nuka Bay.

- G 142. McCarty Glacier from boat. July 30, 1909.
- G 143. Here reproduced as Plate XXXVII, A. East part of front of McCarty Glacier from point A, figure 13. July 30, 1909.
- G 144. Here reproduced as Plate XXXVII, B. Central part of front of McCarty Glacier from point A, figure 13. July 30, 1909.
- G 145. Here reproduced as Plate XXXIX, A. East part of front of Yalik Glacier from point A, figure 15. August 7, 1909.
- G 146. Central and western part of front of Yalik Glacier from point A, figure 17. August 7, 1909.



1. EAST PART OF FRONT OF YALIK GLACIER

From point A, figure 17 August 7, 1909. Photograph G 145.



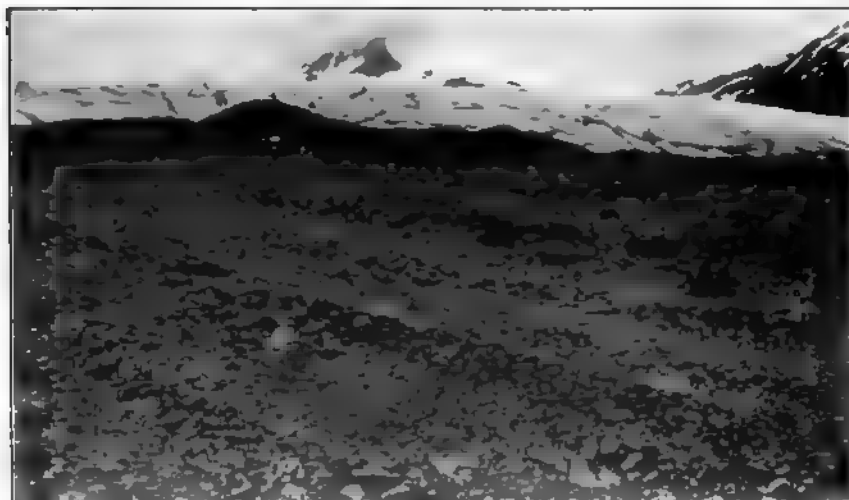
2. EAST PART OF FRONT OF PETROF GLACIER

From point A, figure 18. August 8, 1909. Photograph G 238.



A. WEST PART OF FRONT OF PETROF GLACIER

From point B, figure 18. August 8, 1909. Photograph G 240.



B. SMALL RIDGES IN FRONT OF PETROF GLACIER

August 8, 1909. Photograph G 239.

G 147. Central and eastern part of front of Petrof Glacier from boat. August 9, 1909.

G 228. Here reproduced as Plate XXXVIII, *A*. West part of front of McCarty Glacier from point B, figure 13. July 30, 1909. Point B is a small gravelly knoll about 7 feet high; it is the nearest to the sea and highest grassy knoll on the glacial flat, and is about 600 feet north of the beach.

G 229. West side of McCarty Glacier from point C, figure 13. July 30, 1909. Point C is a small bare gravelly knoll at the edge of the bare zone and a few hundred feet south of a forested rock ridge.

G 230. McCarty Glacier from boat. July 31, 1909.

G 231. Split Glacier from point E, figure 15. August 2, 1909. Point E is the highest bare rock knob on the east side of the central ridge in front of this glacier. This point is marked by a cross cut in the bedrock and by a cairn. Point E is shown in Pl. XXXVIII, *B*.

G 232. Here reproduced as Plate XXIV, *B*. Split glacier from point F, figure 15. August 2, 1909. Point F is the northmost and highest point of a bare gravel ridge, from which point there is a rather steep descent east to a stream leading from the glacier.

G 233. Here reproduced as Plate XXXVIII, *B*. Split Glacier from point G, figure 15. August 2, 1909. Point G is marked by a cairn, and bearings from it are as follows: (1) N. $66^{\circ} 30'$ E. to a prominent fall, about 1,000 feet above the sea, east of the glacier; (2) N. $20^{\circ} 30'$ E. to the buff-colored cliff on which is point E; (3) N. 28° W. to the mountain shoulder (appearing as a sharp peak from point G), about 1,200 feet above sea level, above the west part of the front of the glacier.

G 234. Split Glacier from boat. August 3, 1909.

G 235. Yalik Glacier from boat. August 6, 1909.

G 236. Yalik Glacier from boat. August 6, 1909.

G 237. West part of front of Petrof Glacier from point A, figure 18. August 8, 1909. Point A is the top of a prominent gravel knoll on the east side of the valley, and bearings from it are as follows: (1) N. 46° E. to a brownish-pink rock lens near the east part of the front of the glacier; (2) N. 65° W. to the top of the prominent mountain which lies about a mile and a half west of the front of the glacier; (3) S. 39° W. to a large cleft in the north side, and two-thirds of the distance to the top, of the prominent mountain (Brown Mountain) near the coast and south of the glacial flat.

G 238. Here reproduced as Plate XXXIX, *B*. East part of front of Petrof Glacier from point A, figure 18. August 8, 1909.

G 239. Here reproduced as Plate XL, *B*. Small ridges in front of Petrof Glacier. August 8, 1909.

G 240. Here reproduced as Plate XL, *A*. West part of front of Petrof Glacier from point B, figure 18. August 8, 1909. From point B bearings are as follows: (1) S. 41° E. to the south end of the timber on the ridge southeast of the front of the glacier; (2) S. 29° W. to the cleft mentioned under G 237; (3) S. 38° W. to the middle and highest of the three sharp conical points on the west flank of Brown Mountain.

PORT DICK.

Port Dick, named by Portlock in 1786, is an embayment of considerable size just northwest of Point Gore. About a mile northwest of the head of the northern arm of Port Dick is a small glacier which terminated in 1909 about 1,000 feet above the sea. This is, as far as our knowledge goes, the most southern glacier on the Kenai Peninsula. About 3 miles north-northeast of the head of the above arm is another glacier, which also drains into Port Dick. Some of the maps¹ show a glacier (the Southern) coming close to sea level north

¹ Bull. U. S. Geol. Survey No. 277, 1906, Pl. 13. Chart U. S. Coast and Geod. Survey No. 8502, 1907.

of the end of the west arm of Port Dick and extending north to near the head of Tutka Bay of Kachemak Bay. There is no evidence of a glacier in the lower 4 miles of the valley which enters the end of the west arm of Port Dick from the north, and the stream in this valley, as well as the stream here entering Port Dick from the west, is clear and shows no evidence of glacial waters. Evidently the Southern Glacier, if such a glacier exists, lies entirely northwest of the divide between Port Dick and Tutka Bay and drains only into the latter bay.

KACHEMAK BAY.

On the southeastern side of Kachemak Bay of Cook Inlet are at least four glaciers, which approach but do not reach the sea. These are the most westerly glaciers of which we have knowledge on the Kenai Peninsula. From southwest to northeast these glaciers are the Southern, which drains into Tutka Bay, the Doroshin, the Wossnes-senski, and the Grewingk. These glaciers, except the last, have not been studied and described, at least so far as we have been able to discover. The Grewingk was visited by W. H. Dall in 1880 and in 1892 and 1895.¹ The results of his mapping of this glacier were incorporated in charts of the United States Coast and Geodetic Survey. Dall again visited the Grewingk Glacier with Gilbert in 1899, and the latter has described this glacier in detail.² The writers have not seen the glaciers of Kachemak Bay.

SUMMARY.

Some of the glaciers here described—the Valdez, the Shoup, the Columbia, the glaciers of Port Wells, and the Bear—have been under observation at two or more times during a period of 10 years. There are practically no observations, however, fixing definitely the positions of the glacial fronts of the others earlier than 1908 or 1909, and for information regarding their retreat or advance recourse must be had to the relations of their fronts in 1908 or 1909 to the surroundings and especially to the forest growth which mantles most of the coast from sea level to an altitude of several hundred feet. Reference is here made to the slow-growing coniferous forest and not to deciduous alders and cottonwoods, which in some places, especially on sand and gravel areas, rapidly cover ground recently abandoned by glaciers or by glacial drainage. Much of this forest consists of a mature growth of large trees on a moss-and-soil zone of considerable thickness. Trees 100 years of age, and some probably much older, are thought to be abundant, and these are growing among fallen and decaying trunks

¹ Dall, W. H., Bull. Phil. Soc. of Washington, vol. 6, 1884, pp. 33-36; Bull. U. S. Geol. Survey No. 84, 1892; Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, p. 789.

² Gilbert, G. K., Alaska, vol. 3, Harriman Alaska Expedition, 1904, pp. 97-102.

of similar size. The time necessary for the development of such a mature forest is undoubtedly much longer than the age of the oldest living trees, and consequently there seems to be good reason to affirm that the present conditions of forest growth were present toward the end of the eighteenth century, when Cook and Vancouver visited this district. The expression "since the growth of the present forest," which is here used of necessity many times, refers, then, to an indefinite period, which can not be less than 100 years, and which in all probability is of several centuries duration.

The forest undoubtedly varies in age from place to place depending on environment. Our observations lead to the conclusion that on sand and gravel areas the deciduous forest is likely to be established first, and that this first forest is later replaced by the slower growing conifers; on areas underlain by till the evergreen forest is sometimes developed directly, and the earlier cycle of deciduous growth is entirely lacking. The growth of the coniferous forest and even that of the smaller herbaceous plants is a slower process than is sometimes thought, as can be determined from dated photographs showing conditions along the front of the Columbia Glacier. The location of the forest with reference to the open sea and its warm moist winds is also an important ecologic factor. The luxuriant forest in front of the Columbia, Bainbridge, and Northwestern glaciers may, therefore, be no older and may even be considerably younger than the sparse, small, and stunted forest toward the heads of such inlets as Unakwik Bay, Port Wells, and Icy Bay; indeed, at the extreme heads of some inlets conditions may be so unfavorable as to prohibit forest growth entirely.

The Valdez Glacier has fluctuated somewhat since 1900, but its front was in 1909 not far from its position at the earlier date. Sometime between 1905 and 1908 there was an advance of 300 feet or more followed by a retreat. Within a century the glacier has probably been considerably in advance of its present position.

The Shoup Glacier has remained nearly stationary during the last 10 years and is now near its maximum position of advance in the last 50 years.

The central part of the Columbia Glacier retreated about 360 feet between 1897 and 1905. In 1908 it advanced 100 feet and in 1909 the advance was continued into the forest, the ice front reaching by August 23, 1909, a point 120 feet in advance of its maximum of 1897. In 1909 the western side of the ice stream was farther in advance than at any time since the growth of the present forest. The maximum recorded on the eastern side of the glacier was perhaps 50 years ago. At some time since the establishment of present conditions the glacier front has been considerably farther back, perhaps a mile or more.

The Meares Glacier changed little between 1905 and 1909, during which period it was near its maximum advance since the growth of the present forest.

The Yale Glacier has shown little change since 1899, and is at present about as far advanced as it has been within the last 50 years, but before this period it was much further advanced than now.

The Harvard Glacier showed little change between 1899 and 1905, but in 1909 had advanced half a mile. This and the other glaciers of College Fiord have probably been much larger within a century.

The Smith Glacier has advanced about 600 feet since 1899, and this advance probably was made since 1905.

The Bryn Mawr Glacier in 1905 was in approximately the same position as in 1899. In 1909 it had advanced about 500 feet.

The Vassar Glacier has probably had the same history since 1899 as the Bryn Mawr, its advance since 1905 being about 500 feet.

The Wellesley Glacier was apparently as far advanced in 1909 as at any time within the five previous years, but was probably more advanced some 15 years ago.

The Barry Glacier shows more retreat in the last 10 years than any other ice stream here described. Its maximum advance since the growth of the present forest was reached perhaps 25 years ago. From 1899 to 1905 this glacier retreated 1.2 miles; from 1905 to 1908, 0.4 mile; from 1908 to 1909, 0.5 mile. This is a total retreat of 2.1 miles in the last 10 years.

The Serpentine Glacier reached its maximum since the growth of the present forest a few years before 1899. In 1905 its position was approximately the same as in 1899, but in 1909 the ice front had retreated a quarter of a mile and was half a mile farther back than the maximum position before 1899.

The Baker Glacier shows a small retreat between 1899 and 1905, but in 1909 the ice was probably farther advanced than four years earlier.

The Surprise Glacier retreated 0.1 mile in recent years before 1899. This retreat was probably continued in 1905, and in 1909 the glacier was 1.1 miles farther back than its maximum in recent years.

The Cataract Glacier has probably varied little in the last 10 years and has not been much in advance of its present position in the last 25 years.

The Harriman Glacier retreated on its eastern side about 700 feet between 1899 and 1909, half of this retreat taking place before 1905. The western side of the glacier has changed little since 1899.

The Dirty Glacier was a little more advanced in 1905 than in 1909.

The Toboggan Glacier retreated 723 feet between 1905 and 1909, but at some period between these dates it was farther advanced than in 1905. This glacier has recently reached its maximum advance since the growth of the present forest.

The glaciers of Harriman Fiord have probably not, within the last century or two, been very much in advance of the maxima recorded on page 70.

The Tebenkof Glacier has retreated a short distance in the last 10 or 15 years.

The Blackstone Glacier has retreated about 3 miles within the last 200 years or more.

The Ultramarine Glacier shows some retreat in the last few years.

The Nellie Juan Glacier has in the last 20 years or more retreated 500 feet from its maximum advance since the growth of the present forest.

The Falling Glacier has retreated some in the last few years.

The Taylor Glacier has retreated about a quarter of a mile in the last few years.

The Princeton and Chenega glaciers were in about the same position in 1909 as in 1908. At some previous time, within 100 years, these glaciers filled Nassau Fiord out to Icy Bay, being then about 2 miles in advance of their present positions.

The Tiger Glacier advanced probably 100 feet between the summers of 1908 and 1909.

The Bainbridge Glacier in 1908 was close to its maximum since the growth of the present forest.

The Puget Glacier has retreated in recent years; before the retreat began it was at its maximum advance since the growth of the present forest.

The Excelsior and Ellsworth glaciers have also retreated in recent years.

The Bear Glacier was essentially in the same position in 1909 as in 1905, but perhaps 25 years ago it reached its maximum advance since the growth of the present forest, bringing it about a quarter of a mile in front of its present position. At some date within 25 years the glacier was considerably farther back than it is at present.

The Aialik Glacier is now about a quarter of a mile farther back than it was some 10 years ago, when it reached its maximum within recent times.

The Pederson Glacier some 15 years ago was about a third of a mile in advance of its present position. At that date it reached its maximum since the growth of the present forest.

The Holgate Glacier has within recent years been about a mile in advance of its present position.

The Northwestern Glacier some 10 or 15 years ago was about a quarter of a mile in front of its present position. That advanced position is the maximum since the growth of the present forest.

The McCarty Glacier has retreated about a quarter of a mile within the last 50 years or less; at some time during that period it occupied its most advanced position since the growth of the present forest.

The Split Glacier is now about a quarter of a mile farther back than its maximum position since the growth of the present forest.

The Yalik and Petrof glaciers have also retreated from their maximum positions since the growth of the present forest.

The Barry, Surprise, Chenega, Princeton, and Holgate glaciers have shown a considerable retreat within recent years; the amount of this retreat ranges from a mile to more than 2 miles. The retreat of the Barry and Surprise glaciers has taken place mainly within the last 10 years. The retreat of the others has covered a longer period—that of some perhaps 50 or more years. The Columbia and Bainbridge glaciers have advanced recently to their maximum positions since the growth of the present forest, and the Harvard Glacier and the glaciers on the west side of College Fiord have advanced in the last 10 years, the main advance taking place since 1905. Some of the glaciers have shown alternate retreat and advance since they have been under observation, and very probably many others would show similar fluctuations were there sufficient data to reveal them. These fluctuations take place, not only in different glaciers but also in different parts of the same glacier. Retreats are easily recognized, but advances, unless there are accurate records of previous positions, are difficult to measure and sometimes to detect; thus some of the glaciers that are now in a position somewhat back of their maxima since the growth of the present forest may still be much in advance of their position a few years ago.

- The history of the glaciation of the district under discussion includes the formation of an extensive Pleistocene ice sheet, which extended to the sea and reached upward on the mountains to altitudes which decrease toward the main coast line where the glaciation extended about 2,000 feet above present sea level. Since this period of maximum glaciation there has been a marked decrease in the extent of the ice-covered areas, until now only valley glaciers reach the sea. This withdrawal of the ice was probably punctuated by temporary advances and the present is only an epoch in the long history since the maximum Pleistocene glaciation. Earth movements have also played a part, as yet little known, in this history; changes on Prince William Sound are still taking place,¹ and since the maximum period of glaciation there has been a considerable sinking of the coast line in much of the area and between Resurrection and Nuka bays there are numerous drowned cirques. (See Pl. II, in pocket.) On the whole, the glaciers here studied do not give uniform evidence as to a general retreat or a general advance within the last half century; some are evidently in a period of retreat and others in a period of advance, and the general balance between retreat and advance can not be accurately determined by data now at hand.

¹ Grant, U. S., and Higgins, D. F., Reconnaissance of the geology and mineral resources of Prince William Sound, Alaska: Bull. U. S. Geol. Survey No. 443, 1910, p. 17.

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- *The geography and geology of Alaska, a summary of existing knowledge, by A. H. Brooks, with a section on climate, by Cleveland Abbe, jr., and a topographic map and description thereof, by R. U. Goode. Professional Paper 45, 1906, 327 pp. \$1.
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- *The mining industry in 1907, by A. H. Brooks. In Bulletin 345, 1908, pp. 30-53. 45 cents.
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- Alaska coal and its utilization, by A. H. Brooks. In Bulletin 442, 1910, pp. 47-100.
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- *The distribution of mineral resources in Alaska, by A. H. Brooks. In Bulletin 345, pp. 18-29. 45 cents.
- Mineral resources of Alaska, by A. H. Brooks. In Bulletin 394, 1909, pp. 172-207.
- *Methods and costs of gravel and placer mining in Alaska, by C. W. Purington. Bulletin 263, 1905, 362 pp. 35 cents. Abstract in *Bulletin 259, 1905, pp. 32-46. 15 cents.
- *Prospecting and mining gold placers in Alaska, by J. P. Hutchins. In Bulletin 345, 1908, pp. 54-77. 45 cents.
- *Geographic dictionary of Alaska, by Marcus Baker; second edition by James McCormick. Bulletin 299, 1906, 690 pp. 50 cents.
- *Water-supply investigations in Alaska in 1906-7, by F. F. Henshaw and C. C. Covert. Water-Supply Paper 218, 1908, 156 pp. 25 cents.

Maps.

- *Alaska, topographic map of; scale 1:2,500,000; preliminary edition, by R. U. Goode. Contained in Professional Paper 45. \$1. Not published separately.
- *Map of Alaska showing distribution of mineral resources; scale, 1:5,000,000; by A. H. Brooks. Contained in Bulletin 345. 45 cents.
- Map of Alaska; scale, 1:5,000,000; by Alfred H. Brooks.
- Map of Alaska showing distribution of metalliferous deposits, by A. H. Brooks. Contained in Bulletin 480. Not issued separately.
- Map showing distribution of mineral resources in Alaska, by A. H. Brooks; scale, 1:5,000,000. Price 20 cents. Also included in *Bulletin 520. 50 cents.

SOUTHEASTERN ALASKA.

- *Preliminary report on the Ketchikan mining district, Alaska, with an introductory sketch of the geology of southeastern Alaska, by Alfred H. Brooks. Professional Paper 1, 1902, 120 pp. 25 cents.
- *The Porcupine placer district, Alaska, by C. W. Wright. Bulletin 236, 1904, 35 pp. 15 cents.
- *The Treadwell ore deposits, by A. C. Spencer. In Bulletin 259, 1905, pp. 69-87. 15 cents.
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- The occurrence of iron ore near Haines, by Adolph Knopf. In Bulletin 442, 1910, pp. 144-146.
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- The Eagle River region, southeastern Alaska, by Adolph Knopf, including detailed geologic and topographic maps. Bulletin 502, 1912, 61 pp.
- The Sitka mining district, Alaska, by Adolph Knopf. Bulletin 504, 1912, 32 pp.
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BULLETIN 526 PLATE I

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- Grand Central quadrangle, Seward Peninsula; No. 646 A; scale, 1:62,500; by T. G. Gerdine.
- Nome quadrangle, Seward Peninsula; No. 646 B; scale, 1:62,500; by T. G. Gerdine.
- Solomon quadrangle, Seward Peninsula; No. 646 D; scale, 1:62,500; by T. G. Gerdine.

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- Seward Peninsula, northwestern portion of, topographic reconnaissance of; scale, 1:250,000; by T. G. Gerdine.
- Seward Peninsula, southern portion of, topographic reconnaissance of; scale, 1:250,000; by T. G. Gerdine.
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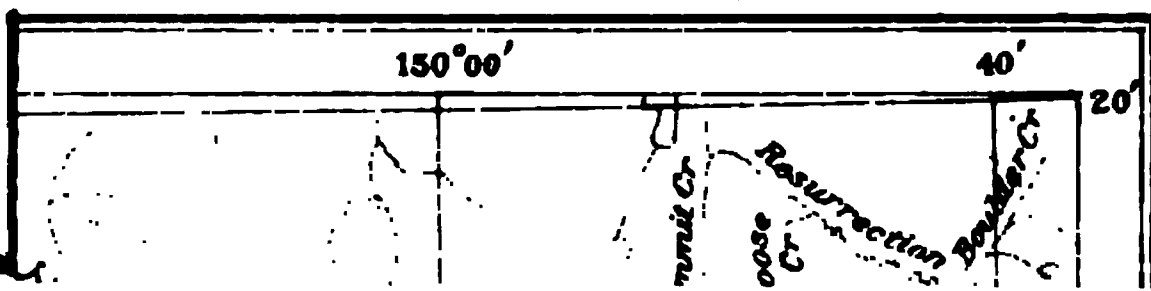
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BULLETIN 526 PLATE II



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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

BULLETIN 527

ORE DEPOSITS
OF THE
HELENA MINING REGION
MONTANA

BY

ADOLPH KNOPF



WASHINGTON
GOVERNMENT PRINTING OFFICE
1913

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ORE DEPOSITS OF THE HELENA MINING REGION, MONTANA.

By ADOLPH KNOPF.

OUTLINE OF REPORT.

The dominant geologic feature of the Helena mining region is the granite mass which forms the northern extension of a great intrusion in southwestern Montana, known as the Boulder batholith. This body of granitic rock represents an invasion of the upper zones of the earth's crust by an enormous volume of fluid magma in late Cretaceous time. The cover under which the granite cooled was largely stripped off by the prolonged erosion of the Tertiary period and the granite was laid bare and now forms the predominant surface rock of the region.

As a consequence of the granite invasion a series of ore deposits, the principal source of the metallic wealth of the region, was formed around the margin of the granite and in the roof rocks overlying it.

The rocks of the region may be broadly subdivided with reference to the great granite mass as (1) those formed prior to its intrusion, and (2) those formed subsequent to its intrusion—in short, as pre-batholithic and as postbatholithic rocks. Of these two groups the prebatholithic rocks are the main repositories of the ore bodies of the region.

The prebatholithic rocks consist principally of sedimentary rocks which range in age from Algonkian to Cretaceous. They include mainly limestone, shale, and quartzite and lie in angular conformity from the lowermost member to the top of the series. These rocks are present chiefly in the northern part of the region. They are overlain by andesite and latite lavas and breccias which are definitely known to be post-Jurassic and are probably of late Cretaceous age. The andesites and associated latites are the youngest rocks intruded by the granite, save perhaps a small area of thermally metamorphosed sandstones overlying them west of Helena.

After the andesites had been erupted the rocks were folded; subsequently the granite magma came to place beneath the region. The granite broke irregularly across the folds of the stratified rocks, the most notable example being the truncation of the southern limb of

the Prickly Pear dome. This is shown to best advantage south of Helena, where the strata dip steeply toward the batholith. At other localities, however, the covering rocks of the batholith—principally andesites—dip away from the granite.

The granitic rock of the Boulder batholith is termed a quartz monzonite because of its high plagioclase content. It is composed of plagioclase (near labradorite), orthoclase, quartz, biotite, and hornblende. As a whole, the mineral and chemical composition is remarkably uniform and homogeneous.

Large intrusions of aplite in irregular masses and dikes are common throughout the area of the batholith and constitute 5 per cent of its superficies.

The covering rocks, forming a roof of unknown thickness under which the granite came to place, crystallized, and cooled, consisted principally of andesites and latites, remnants of which still remain within the central portion of the batholith. The most extensive of these roof remnants is the large andesitic area west of Wickes, and this has been the great repository of the mineral wealth of the region.

A series of dacites, comprising lavas, breccias, and tuffs, locally 2,400 feet thick, rest on the deeply eroded surface of the granite and andesite. In the southwest corner of the region they form part of an extensive area extending to Butte and forming Big Butte at that city. They were formed contemporaneously with the lake beds west of Butte and are of upper Miocene age.

Rhyolites also rest on the eroded surface of the granite and the older rocks. Their relation to the dacites was not determinable. They were erupted on a surface whose relief was much like that of the present topography, and they are apparently the youngest bedrock formation in the region. At the head of Tennile Creek, in the Rimini district, they have been mineralized and constitute low-grade gold ore.

The ore deposits fall into two distinct groups, widely separated in time of origin. The older are late Cretaceous or early Tertiary in age, the younger are post-Miocene.

The older ore bodies are mainly silver-lead and gold-silver deposits. In metallic content they contrast strongly with the ores of the near-by Butte district, which are predominantly copper ores, although formerly silver ores were of importance. The scarcity of copper deposits in the Helena region is a notable feature, doubly so from the fact that the deposits belong to the same metallogenetic province as those of Butte, being formed at approximately the same time and presumably from the same magma.

The ore bodies of the older group have furnished the greater part of the production of the region; in fact, the value of their output has been roughly three times that of the post-Miocene deposits.

The silver-lead deposits constitute the prevailing type of ore body of the Cretaceous deposits. They are commonly situated near the contact of the granite and the rocks invaded by it. Hence, as a rule, they are inclosed in andesite or granite. The ore bodies are replacement-fissure lodes containing galena, sphalerite, pyrite, and arsenopyrite.

The older ore bodies are commonly tourmaline bearing. In certain deposits, as at Rimini, tourmaline is extremely abundant; in fact, it is there developed in the same abundance that characterizes the tin lodes of Cornwall. The premier ore deposit of the region—the Alta, credited with an output of \$32,000,000 in silver-lead ore—shows notable tourmalinization. Three types of tourmalinic lodes with transitions between them are recognized—lead-silver, copper-silver, and gold. The predominant type is the tourmalinic lead-silver, a type that is unique, as far as shown by the literature of ore deposits.

The extreme depth to which any of these deposits has been worked is 1,200 feet. At Rimini, where the extreme depth attained below the present surface is only 600 feet, it is probable that this depth is 2,000 feet below the intrusive contact surface of the granite.

The ores were formed at high temperatures, and it is regarded as probable that the ore-forming solutions were derived from a final differentiate of the quartz monzonite magma.

The post-Miocene ore bodies are essentially precious-metal deposits. They are characterized by the tendency of the quartz gangue to display a cryptocrystalline development, either flinty, chalcedonic, or densely saccharoidal, resembling porcelain. Equally characteristic is the thinly lamellar calcite of the gangue and its pseudomorphic replacement by quartz, forming a type of ore common in so many of the late Tertiary gold fields of the West. These deposits are typically developed in the upper Miocene dacites of Lowland Creek, but their analogues at Marysville, which have yielded \$30,000,000, have furnished the bulk of the output.

The extreme depth attained on veins of this class is 1,600 feet, at the Drumlummon mine, where the lode was found to be barren below the 1,000-foot level, and the greater part of the production has come from above the 500-foot level.

In early days the mines of the district furnished extremely rich surface ores. The evidence, although inadequate, suggests that the richness of the ores was due largely to mechanical concentration and to the elimination of worthless and objectionable constituents. In depth an objectionable amount of zinc in the form of sphalerite appears in many mines, but in the carbonate ores formerly worked the sphalerite had been oxidized and removed in solution. Secondary enrichment, especially such as has led to the production of great bodies of copper ore, has taken place nowhere in the region. The Marysville district is possibly an exception, for the ore bodies there

12 ORE DEPOSITS OF HELENA MINING REGION, MONTANA.

may have been enriched in gold by descending solutions; the evidence, however, is not conclusive, and the indications are that the impoverishment in depth was due, in part at least, to failure in the primary metallization.

GEOGRAPHY.

LOCATION OF THE REGION.

The Helena mining region, as it is termed in this report, is an area of 1,300 square miles in southwestern Montana. A large number of mining camps are included in the confines of this area, among which,

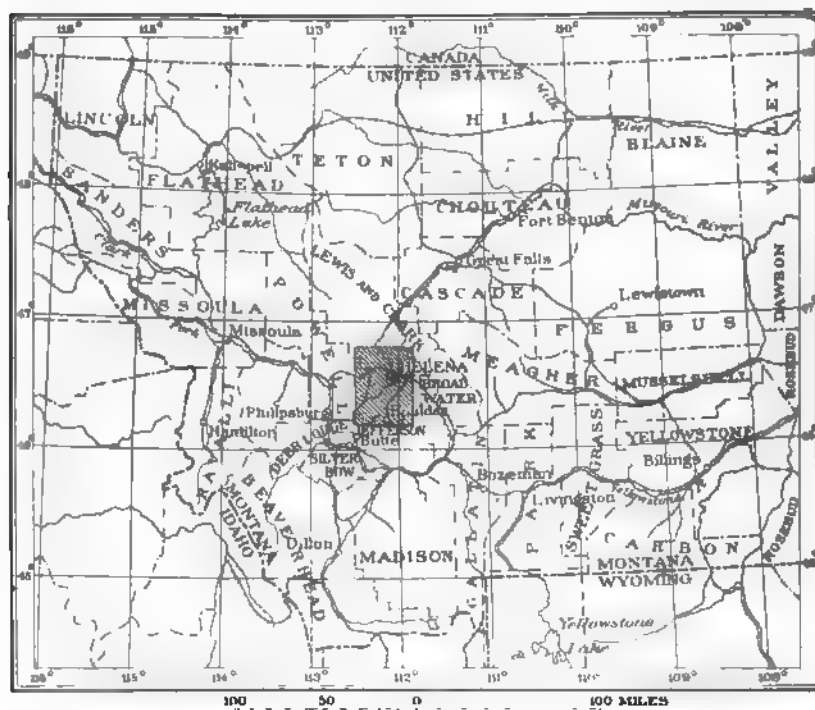


FIGURE 1. Index map showing the location of the Helena mining region, Montana

in point of production, Elkhorn and Marysville are the most important. Helena, however, is by far the largest and best known city in the region, and although it long ago yielded preeminence to other localities as a mining center, it is perhaps still appropriate to speak of this as the Helena mining region, for it was the discovery of the extraordinarily rich placers at Last Chance, where Helena now stands, that led to the development of the mineral wealth of the surrounding territory.

The Marysville mining district is situated in the northwest corner of the region, Elkhorn lies in the southeast corner, and the southwest corner is 14 miles north of Butte.

The area lies within the rectangle formed by parallels $46^{\circ} 12'$ and $46^{\circ} 48'$ north latitude and meridians $111^{\circ} 50'$ and $112^{\circ} 30'$ west longitude. It includes portions of the Helena and the adjoining Fort Logan quadrangles, and accordingly does not form a regular quadrangle of the Geological Survey.

A large part of the area lies within Jefferson County, a part within Lewis and Clark County, and that part west of the Continental Divide in Powell County. A considerable number of organized and unorganized mining districts are included in the region, but these subdivisions are no longer well known nor employed frequently in local usage, so they will not be used in this report.

The region is traversed from east to west by the main line of the Northern Pacific Railway and from north to south by the Havre-Butte branch of the Great Northern Railway; branch lines of the Northern Pacific extend to the mining camps of Marysville, Rimini, and Elkhorn, so that in comparison with most mining regions it is unusually well favored with transportation facilities. Good wagon roads render nearly every part of the area readily accessible.

PHYSICAL FEATURES.

The region, broadly considered, is mountainous and has a considerable and abrupt relief. The western portion constitutes the broad back of the Continental Divide, which here averages 7,000 feet in altitude. The topography, however, is neither rugged nor alpine, but is characterized by smoothly rounded profiles, due to the prevalence of domelike summits.

Red Mountain, 14 miles southwest of Helena, is the highest mountain in the northern part of the region; it attains an altitude of 8,200 feet, and its broad, rounded summit looms up above its fellows for many miles around. The Elkhorn Mountains, on the eastern side of the region, are separated from the mountainous country on the west by the broad Boulder Valley. They are the highest mountains in the region, Elkhorn and Crow peaks reaching a height of 9,300 feet. On the northeast flanks of these peaks are a series of finely developed glacial amphitheaters, whose sheer walls and heavy talus slopes make this the most rugged part of the area.

The largest stream is Boulder River, flowing across the southern part of the region from west to east in a narrow valley deeply sunk between the surrounding mountains. On the east this valley opens out abruptly into the broad valley at Boulder; on the west beyond Bernice it again broadens and shows a fine series of terraces, the highest 250 feet above the stream. The irregular mountainous area through which Boulder River flows, and which forms the larger part of the area concerned in this report, is sometimes known as the Boulder Mountains.

Missouri River crosses the extreme northeast corner of the region. Its principal tributaries are Prickly Pear, Tenmile, and Silver creeks.

The most important stream west of the Continental Divide is Little Blackfoot River, which flows westward beyond the confines of the region, joining Clark Fork at Garrison. The Northern Pacific Railway in crossing the Continental Divide eastward ascends the valley of the Little Blackfoot to Elliston, and thence parallels an affluent from the northeast. The ascent is gradual through a comparatively broad and open valley bordered by smooth, rounded hills. Near Mullan Pass, at the mouth of Dog Creek, there is a wide expanse of flat, so that it is difficult to realize that this is the summit of the Rocky Mountains.

CLIMATE.

The climate is semiarid, the annual precipitation ranging from 10 to 13 inches. The summers are warm and pleasant; the winters are comparatively mild, despite the altitude and inland position of the region. The winter weather is ameliorated by the warm chinook wind that blows from the northwest; snow does not cover the ground in the open valleys during long periods, but disappears before the chinook.

The important climatic elements are given in the subjoined tables.¹

Monthly and annual precipitation, in inches, in the Helena region, Montana.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Helena.....	1.00	0.66	0.83	1.06	2.13	2.26	1.13	0.69	1.13	0.77	0.76	0.79	13.21
Boulder.....	.65	.43	.50	.96	1.66	1.95	1.02	.76	.92	.41	.38	.46	10.00

Mean temperature, in degrees Fahrenheit, in the Helena region, Montana.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Helena.....	20.0	22.7	31.7	42.1	51.8	59.1	66.9	66.2	56.2	45.8	32.3	26.3	43.6
Boulder.....	20.0	21.7	23.2	41.5	49.5	55.9	62.9	62.8	52.2	42.9	31.1	24.7	41.1
Marysville.....	20.9	21.9	25.7	40.4	47.4	55.0	62.9	62.1	51.5	43.0	29.8	25.9	40.5

Average number of days with 0.01 inch or more of precipitation in the Helena region, Montana.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Helena.....	9	7	8	8	12	12	8	5	7	1	7	8	97
Boulder.....	5	4	6	6	8	8	6	4	6	3	4	4	64
Marysville.....	8	7	8	7	14	10	8	6	5	5	7	9	94

¹ These tables are taken from more extended data given by R. F. Young, U. S. Weather Bureau, in the Twelfth Rept. Montana Bur. Agr., Labor, and Industry for 1909 and 1910, pt. 1, pp. 82-91.

Average snowfall, in inches, in the Helena region, Montana.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Helena.....	11.5	6.0	9.6	5.8	1.4	Tr.	0.0	0.0	0.6	3.1	6.5	8.1	54.7
Boulder.....	4.7	4.5	4.9	4.2	1.1	Tr.	0	.6	1.1	.8	2.3	4.4	30.4
Marysville.....	16.2	13.8	18.8	8.1	5.9	.5	Tr.	.2	1.6	5.4	14.9	15.0	100.1

HISTORICAL SKETCH OF MINING.

The first important find of metallic wealth in Montana was the discovery of placer gold at Bannock in 1862. In the following year the far greater discovery at Alder Gulch was made, and from this stream was taken within the next three years \$30,000,000. The extraordinary richness of these placers immediately attracted a large population, and so strong was this influx that within 18 months a town of 10,000 people sprang up, which was named Virginia City. Alder Creek was the longest and most productive creek ever discovered in Montana; 20 miles of stream bed, comprising about 1,000 claims, were worked and yielded a profit at a time when wages were from \$10 to \$14 a day.

Montana was soon overspread by eager prospectors, and in the next few years all the important placers were discovered. Last Chance, on the present site of Helena, was located in the summer of 1864. This was the first important discovery in the region that is the subject of this report. The Whitlatch-Union vein, carrying rich gold ore, was found a few miles south of Helena in September of the same year. Lode and placer discovery were thus contemporaneous. The finding of gold in place caused a quartz excitement which stimulated prospecting all over the Territory.

Last Chance yielded \$16,000,000, the bulk of which was taken out before 1868. Many streams in the vicinity of Helena were also found to be auriferous—Prickly Pear Creek, Nelson Gulch, Silver Creek, and others. In fact some of these prior to the discovery of Last Chance had been found to contain placer gold. Prickly Pear Bars, a few miles east of the site of Helena, were found to be auriferous in August, 1862, and led within a few months to the discovery of gold on Silver Creek. Here Silver City was founded, which became, before Last Chance was organized, the political and commercial center of Lewis and Clark County.

West of the Continental Divide placers were found in 1865 at Ophir Creek, Carpenter Bar, and Snowshoe, small affluents of Little Blackfoot River from the north. Here sprang up Blackfoot City (now called Ophir), which has long ago lapsed into decay. By 1875 the diggings had been abandoned to Chinese. In 1911, however, the gravels at the mouth of Snowshoe Gulch were tested for their possibility as dredging ground.

The silver-lead ores and true silver ores in the vicinity of Wickes, Jefferson, and Clancy were discovered simultaneously with the finding of the placers. The Gregory lode, one of the earliest finds, was located in 1864 by a party going from Alder Gulch to Helena. An American hearth was erected here in 1867 to smelt the ore; this was the second smelter established in Montana, the first being that built at Argenta.

The great need of the Territory at this time was an adequate transportation system, with rail connection with the centers of civilization. By 1870 the placers had been largely exhausted and a period of stagnation set in, for lode mining was not likely to flourish when high freight charges consumed the profits. According to the historian Bancroft, "Freights during the first decade were enormous, costing the country between a million and a half and two millions annually, even after the population had shrunk to 18,000." The chief overland transportation route was Missouri River, by which steamers could reach Fort Benton, 150 miles from Helena, during high-water stages. But this period of high water lasted only 4 to 6 weeks, and steamers were often forced by low water to stop at Fort Union, at the mouth of the Yellowstone. On the completion of the Union Pacific Railroad in 1869 much of the traffic was diverted to this route, Corinne in Utah, being the initial point for freight bound for Montana. In addition to the handicap of high transportation charges most of the ores were of the kind that required expensive metallurgic treatment. Under these adverse conditions only the richest ores could be worked. The ores were either hauled to Fort Benton, thence sent to the seaports, and shipped to Swansea, Wales, or were hauled by wagons to Corinne on the Union Pacific Railroad, a distance of 450 miles, sent to San Francisco, and shipped to Europe.

The Northern Pacific Railway reached Helena in 1883, the first train crossing the Continental Divide west of Helena on August 7, 1883, and the golden spike signaling the completion of the overland road was driven on September 8, 1883, near Garrison.

The advent of the railroad exerted a strong stimulus on the mining industry. During the latter part of 1883 the Helena & Jefferson Railroad was built. This is now part of the Great Falls branch of the Great Northern Railway and connected Helena and Wickes, a distance of 20 miles. In the same year the Helena Mining & Reduction Co. acquired by purchase from the Alta Montana Mining Co. the Alta, Comet, and other well-known mines near Wickes. The smelter at Wickes was rebuilt and enlarged, so that it was for some years the most extensive reduction plant in Montana and drew ores from a large radius, even as far as the Cœur d'Alene district. In 1893 it was shut down and dismantled. The same fate has overtaken the many small smelters built at the various mines throughout the region, so that now the only smelter in operation is the East Helena plant of the American Smelting & Refining Co.

The period from 1883 to 1893 comprises the years during which the bulk of the silver-lead ore was produced. The lode gold of the region has come mainly from the Marysville district. Mining flourished there principally from 1880 to 1900, although during the latter part of the period the yield came largely from the cyanidation of tailings piles.

PRODUCTION.

The total production of the region, including the yield from silver-lead ore, placer gold, and lode gold, is not accurately ascertainable but is roughly in the neighborhood of \$150,000,000. The estimates of placer production are particularly unsatisfactory, and for many of the streams no data are available. The output of Last Chance, the most productive of the placers, is estimated in widely different amounts by different writers, ranging from \$10,000,000 to \$35,000,000. Bancroft's estimate of \$16,000,000 is accepted here.

The total output is distributed as follows: Silver-lead, \$80,000,000; lode gold, \$40,000,000; and placer gold, \$30,000,000. Of these figures probably that for lode gold is entitled to the most confidence.

During 1910 the total production from the deep mines of the region, as compiled from Mineral Resources of the United States for 1910, was \$997,359. Of this amount gold represented \$275,134, and silver, lead, and copper the remainder. The Elkhorn district furnished the preponderant part of the production—\$652,738. Placer mining in the region is now insignificant, and in 1910 yielded only \$4,312.

The total production for 1911 was \$864,050, of which gold constituted \$267,914.

The following table shows that in recent years the production of the region has fluctuated around \$1,000,000.

Production of the Helena mining region, Montana.

1906.....	\$917, 165
1907.....	1, 617, 379
1908.....	1, 118, 884
1909.....	908, 044
1910.....	997, 359
1911.....	864, 050

FIELD WORK AND ACKNOWLEDGMENTS.

Field work was commenced at Helena on June 20 and completed September 24, 1911. While this work was carried on, the writer was efficiently assisted by Henry G. Ferguson, to whom fell most of the task of mapping the areal geology of the region. The examination of the mines and prospects was undertaken mainly by the writer.

During the preparation of this report in the office the writer has availed himself of certain collections of rocks ores, and thin sections from Elkhorn, Marysville, and the Boulder quadrangle, which had been gathered by W. H. Weed and Joseph Barrell for the United States Geological Survey and are now deposited in the United States National Museum. Some of the mines from which they had collected specimens are no longer accessible, and such specimens were often found to be of much value for comparative purposes.

LITERATURE.

The following list includes the principal papers bearing on the geology and ore deposits of the region. The literature concerning the ore deposits is scanty and is limited to papers on the Elkhorn and Marysville districts.

BANCROFT, H. H., History of Washington, Idaho, and Montana, 1848-1889, San Francisco, 1890.

Gives an interesting account of the history of Montana and much valuable information concerning the growth of the mining industry.

BARRELL, JOSEPH, Microscopical petrography of the Elkhorn mining district, Jefferson County, Mont.: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, pp. 511-549.

—— The physical effects of contact metamorphism: Am. Jour. Sci., 4th ser., vol. 13, 1902, pp. 279-296.

A theoretical discussion of contact metamorphism, based largely on the phenomena at Elkhorn, Mont.

—— Geology of the Marysville mining district, Mont.: a study of igneous intrusion and contact metamorphism: Prof. Paper U. S. Geol. Survey No. 57, 1907, 178 pp.

As indicated by the subtitle, this report deals mainly with the phenomena of igneous intrusion and contact metamorphism exhibited at Marysville; it presents the strongest detailed evidence in favor of the magmatic stoping hypothesis yet published.

—— Relative geological importance of continental, littoral, and marine sedimentation: Jour. Geology, vol. 14, 1906, pp. 553-560.

It is argued that the Belt series of Montana is largely of terrestrial origin.

CLAYTON, J. E., The Drumlummon group of veins and their mode of formation: Eng. and Min. Jour., vol. 46, 1888, pp. 85-86, 106-108.

An able study of the structural features of the Drumlummon lode.

GRISWOLD, L. S., The geology of Helena, Mont., and vicinity: Jour. Assoc. Eng. Soc., vol. 20, 1898, pp. 51-68.

A careful description of the character and distribution of the rocks at Helena, accompanied by a geologic map.

KEYES, W. S., Mineral resources of the Territory of Montana: Mineral Resources of the States and Territories west of the Rocky Mountains, 1868, Appendix, pp. 38-56.

Gives many valuable facts concerning the early mining history.

LEESON, M. A., History of Montana, 1739-1885. Chicago, 1885, 1367 pp.

Gives much detailed information concerning the settlement and history of the mining camps.

LINDGREN, WALDEMAR, Relation of the coal of Montana to the older rocks; Appendix B, Eruptive rocks: Tenth Census, vol. 15, 1886, pp. 733-734.

Concludes that the intrusive granite at Mullan Pass is of Jurassic age.

STONE, R. W., Geologic relation of ore deposits in the Elkhorn Mountains, Mont.: Bull. U. S. Geol. Survey No. 470, 1911, pp. 75-98.

Deals principally with the area east of that concerned in this report.

WALCOTT, C. D., Pre-Cambrian fossiliferous formations: Bull. Geol. Soc. America, vol. 10, 1899, pp. 199-244.

In this paper are given the type descriptions of certain divisions of the Belt series.

WEED, W. H., Granite rocks of Butte, Mont., and vicinity: Jour. Geology, vol. 7, 1899, pp. 737-750.

The Boulder batholith is defined in this paper, and chemical analyses of the rock from different localities are given.

——— Mineral vein formation at Boulder Hot Springs, Mont.: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 227-255.

It is shown that the hot waters are forming veins filled with quartz, stilbite, and calcite, and containing small but appreciable amounts of gold and silver.

——— Geology and ore deposits of the Elkhorn mining district, Jefferson County, Mont., with an appendix on the microscopical petrography of the district, by Joseph Barrell: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, pp. 399-549.

——— Gold mines of the Marysville district, Mont.: Bull. U. S. Geol. Survey No. 213, 1903, pp. 88-89.

Outlines briefly some of the salient features of the gold veins at Marysville.

——— Geology and ore deposits of the Butte district, Mont.: Prof. Paper U. S. Geol. Survey No. 74, 1912, pp. 26-30.

Gives a geologic reconnaissance map of the area underlain by the Boulder batholith and a brief description of the general geology.

WINCHELL, H. V. and A. N., Notes on the Blue Bird mine: Econ. Geology, vol. 7, 1912, pp. 287-294.

Attention is called to the tourmaliniferous character of the ore, and various rocks occurring at the mine are described petrographically.

GENERAL GEOLOGY.

CHARACTER AND DISTRIBUTION OF THE ROCKS.

Sedimentary rocks occur in the main only in the northern part of the region. They consist for the most part of an apparently conformable succession of limestone, shale, sandstone, and quartzite, ranging in age from Algonkian to Cretaceous. At certain localities deposits of poorly consolidated clays, gravels, and tuffs of Tertiary age—so-called lake beds—rest unconformably on the older rocks.

The prevailing rocks of the region are igneous - andesite and latite, quartz monzonite and aplite, dacite, and rhyolite. Of these the quartz monzonite predominates; it is of intrusive origin and invades all the rocks older in age than the lake beds. The other igneous rocks, except the aplite, which is closely associated with the quartz monzonite, are of extrusive origin and form thick stratiform series of lavas, tuffs, and breccias. The andesites and latites are older than the quartz monzonite, and the dacites and rhyolites are younger.

The distribution of these rocks is shown on the geologic map forming Plate I of this report. The small scale of the map—1:250,000 or approximately 4 miles to 1 inch—allows the broader features only to be shown. It is believed that for the greater part of the area the boundaries of the geologic formations as given are accurate to scale. An earlier geologic map of a portion of this region, based on reconnaissance work, appeared as Plate I in the report on the Butte district.¹ In that map, while in press, certain new data obtained during the present investigation were incorporated, with Mr. Weed's concurrence, but the older map was not completely revised.

Plate VII (p. 86) of this report shows the areal geology of Helena and vicinity on a scale of 1:62,500. This map was prepared by Mr. Weed and his assistants, and is published for the first time in this report in order to show the detailed distribution of the rocks in a district which is highly interesting geologically—details necessarily lost on the small-scale map of Plate I.

PROTEROZOIC ROCKS.

ALGONKIAN SYSTEM.

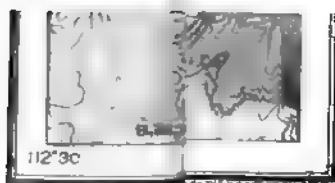
BELT SERIES.

The oldest rocks of the region are a series of limestones and shales known collectively as the Belt series. Walcott recognizes eight formations, aggregating at the maximum 12,000 feet in thickness. The rocks occupy a large area in the northern part of the region of this report, but only the four uppermost formations are present. These in ascending order are known as the Spokane shale, Empire shale, Helena limestone, and Marsh shale. At Helena these attain a thickness of 3,300 feet, of which the Helena limestone makes up 2,400 feet, increasing to 4,000 feet at Marysville, according to Barrell.

In the present mapping no attempt was made to differentiate the various formations of the Belt series, and all rocks below the Flathead quartzite were mapped under the same symbol. They are the rocks termed by W. M. Davis "the barren slates, shales, and sandstones," encountered in the area between Helena and Mullan Pass on the Continental Divide and regarded as of probable Cambrian age.² They were assigned to the Algonkian system by Walcott, who believes that the unconformity at the base of the Flathead quartzite of Middle Cambrian age is of sufficient magnitude to justify the placing of the Belt series in the pre-Cambrian.

¹ Weed, W. H., Geology and ore deposits of the Butte district, Mont.: Prof. Paper U. S. Geol. Survey No. 74, 1912.

² Tenth Census, vol. 15, 1886, p. 703.



Base map from Ralph Knopf
 Fort Logan at Ft. Ferguson,
 U. S. Geologic from
 additional data, R. W. Stone,
 unpublished map of
 Elkhorn Mountain

Surveyed in 1886
 and 1910 to Dec. ; 62d Cong., 3d Sess.

PALEOZOIC ROCKS.**CAMBRIAN AND DEVONIAN SYSTEMS.**

The Paleozoic rocks below the Madison limestone (Mississippian, or lower Carboniferous) comprise a conformable series, consisting dominantly of limestones, with some shale and quartzite. The aggregate thickness is estimated to be 2,300 feet and includes rocks of Cambrian and Devonian ages. Owing to the fact that the formations, except the Flathead quartzite, are not readily discriminable throughout the region the Paleozoic rocks below the Madison limestone have been mapped as a unit.

The lowest formation of the Paleozoic is a persistent and easily recognizable series of quartzites, known as the Flathead quartzite. It consists of a highly lithified, vitreous, coarse siliceous quartzite, stratified in beds commonly exceeding 1 foot in thickness. It is normally white, but in weathering takes on characteristically a red tint and in places displays cross-bedding. The thickness of the quartzite ranges from 80 to 180 feet.

The Flathead quartzite forms prominent outcrops and is well exposed. The contact with the underlying Belt series can be traced mile after mile northwest from Helena; it was found that the quartzite rests on the subjacent rocks in strict angular accordence. In some places it overlies the Helena limestone, in others the Marsh shale. The basal portion of the quartzite, nowhere more than a few feet thick, is slightly conglomeratic, the kind of pebbles composing it varying with the character of the underlying rocks. It is believed by Walcott that several thousand feet of strata were removed before the Flathead was laid down, and this is held to prove that a profound unconformity separates the Flathead from the underlying Belt series.

Above the quartzite, which is so prominent a horizon marker, is a great thickness of limestone strata, with interstratified shales of Cambrian and Devonian age. Details concerning these rocks are given in the description of the local geology of Helena (pp. 86-98).

CARBONIFEROUS SYSTEM.**MADISON LIMESTONE.**

The Madison limestone is prominently developed in the northern part of the region. Its basal member is a dense dark gray-blue limestone, which contains crinoid remains and other fossils and is pierced by innumerable tremolite needles. This member seems to range in thickness from 100 to 200 feet. Above this comes a heavy succession of thickly bedded, coarsely crystalline limestone, which commonly forms bold outcrops of dazzling whiteness.

The total thickness at Helena, according to Weed, is 2,600 feet. The age is Mississippian (lower Carboniferous).

QUADRANT QUARTZITE.

The Quadrant quartzite overlies the Madison limestone conformably. It consists predominantly of quartzite and ranges in thickness from 190 to 500 feet in the Helena area. The quartzite has a characteristic appearance that distinguishes it readily from the other quartzites of the region. It is a light-gray rock of dense, almost cherty texture and outcrops show typical rough hackly surfaces. As a rule the bedding is neither clearly nor positively recognizable. The age of the formation here correlated with the typical Quadrant is probably Pennsylvanian (upper Carboniferous). To the west, in the Philipsburg quadrangle, Calkins obtained Pennsylvanian fossils from the Quadrant formation. In other areas to the east, however, rocks referred to the Quadrant formation have yielded Mississippian fossils.

Phosphate rock of good grade was found in 1911 by J. T. Pardee, of the Geological Survey, near the top of the Quadrant quartzite in the town of Elliston.

MESOZOIC ROCKS.**JURASSIC AND CRETACEOUS SEDIMENTARY ROCKS.**

Rocks definitely determined as of Jurassic age occur at Elliston, where they overlie the Quadrant quartzite in angular concordance.

The beds of determined Jurassic age are buff-weathering arenaceous limestones and some purer limestones, aggregating 50 feet in thickness, referable to the Ellis formation. At the base, as exposed at Elliston, is a sill of diorite porphyry 25 feet in thickness. The basal beds are highly fossiliferous; above them, and possibly a part of the same formation, rests a banded sandstone, as a rule remarkably cross-bedded, with numerous unconformities between the different sets of cross-bedded laminae. The sandstone is a coarse quartzose rock, carrying numerous minute black chert particles, which impart a speckled appearance to the rock. In places fragments of lignitized vegetal matter, some over a foot long, were found. The section immediately at Elliston shows a thickness of several hundred feet of this sandstone, although there are a few intercalated beds of limestone and of a soft, greenish, conchoidally breaking shale.

The fossils were submitted to T. W. Stanton, who reports:

7212 No. 1. Elliston, Helena quadrangle, Mont.

Pentacrinus asteriscus Meek and Hayden.

Camptonectes pertenuistriatus Hall and Whitfield.

Pseudomonotis (*Eumicrotis*) *curta* (Hall).

Undetermined gastropod casts.

Cardioceras ? sp. (small fragment).

This lot is from the marine Jurassic Ellis formation.

Fossils were found, apparently at the same locality, by Lindgren in 1883 and were referred also to the Jurassic by Whitfield.¹

There is no evidence of unconformity between the Ellis formation and the underlying Carboniferous rocks at Elliston. At Philipsburg, 75 miles to the west, however, the Ellis formation, although resting in angular concordance on the underlying Carboniferous, has a basal conglomerate holding pebbles of Carboniferous and older rocks. An erosion interval is therefore proved.² The maximum thickness of the Ellis formation at Philipsburg is 430 feet.

In the region surrounding Elliston there is an extensive development of coarse-grained speckled sandstone lying conformably above the known Jurassic rocks. The sandstone is commonly cross-bedded and semi-quartzitic in appearance. A specimen of dark-gray cross-bedded sandstone from the summit of the 7,000-foot ridge southwest of Elliston was found microscopically to be composed of particles of quartz, black chert, and shale. Considerable secondary quartz in optical continuity with the original grains had grown around the quartz particles. Some few of the quartz grains (0.5 millimeter in diameter) are remarkably perfectly rounded; the chert fragments are subangular.

Limestone, shale, and conglomerate are associated with the cross-bedded sandstone in small amount. Toward the top the rocks apparently grade into the andesite and latite series. Limestones of like appearance and fossil content (obscure fresh-water shells) are interstratified with the volcanic rocks above and the sedimentary rocks below.

These rocks are referred to the Cretaceous, but the line between them and the underlying Jurassic was not determined, and the entire assemblage, Jurassic and Cretaceous, is shown under one symbol on the geologic map.

Rocks of probable Cretaceous age occur at other localities around the margin of the Boulder batholith and even within it, as roof remnants. They occur at Elkhorn, where they are termed by Weed³ the Crow Ridge series, north of Rimini, south of Helena, and at the head of Basin Creek, where they form part of the cover of the batholith.

IGNEOUS ROCKS.

ANDESITES AND LATITES.

OCCURRENCE.

The remnants of the roof of the Boulder batholith consist principally of andesitic rocks, comprising a bedded series of lavas, breccias, and tuffs, with some interstratified quartzite, shale, and limestone. At most localities the truly volcanic portion predominates.

¹ Tenth Census, vol. 15, 1886, p. 703.

² Emmons, W. H., and Calkins, F. C., Prof. Paper U. S. Geol. Survey No. 78, 1913, p. 75.

³ Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, p. 440.

Rocks of andesitic character are developed also in great volume on both the eastern and western borders of the batholith. As a rule breccias and tuffs form the bulk of the andesite and latite series; they predominate at Elkhorn on the east and form practically the entire series on the west. The breccias are in places rather coarse; at Cliff Mountain, which displays a scarp of stratified breccias (Pl. II A), some of the included blocks of andesite are 3 feet long. At this locality beds of hard green and black shales are interstratified with the breccias. Sedimentary rocks are found at other places, as east of Thunderbolt Mountain, where andesite, breccia, banded tuff, and hard shale are interstratified. Fossiliferous limestone carrying fresh-water forms occurs southwest of Elliston.

Where the underlying rocks are exposed the andesites rest on them in angular accordance. At one locality only, at the mouth of the canyon of Tenmile Creek, do sedimentary rocks overlie the andesites. These rocks are thermally metamorphosed sediments, mainly of original arenaceous character. Quartzites, some of great purity, are common, but most are partly micaceous. These rocks, as a whole, appear to correspond to Weed's Cretaceous of the Helena district. Near the contact of the andesitic rocks and the overlying sedimentary rocks there is apparently an interstratification of both kinds.

On the eastern side of the batholith, at Elkhorn, the andesitic rocks dip eastward at a gentle angle away from the granite; on the west, at Cliff Mountain, they dip westward at angles of 15° to 20° away from the batholith, passing beneath the soft Tertiary deposits of Deer Lodge Valley. In the areas lying within the batholith steeper dips occur, some reaching 45° , and the strike differs greatly from place to place.

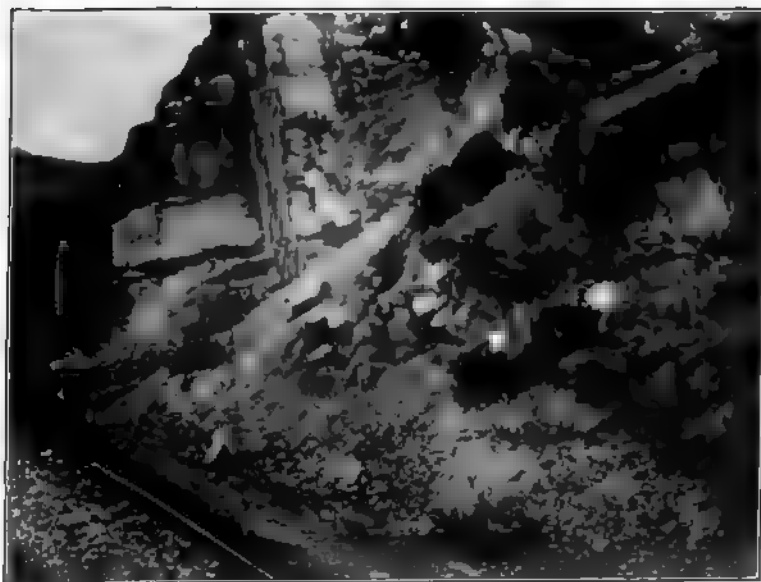
The andesite and latite series is of considerable economic interest, because it forms the country rock at some of the important mines. In fact, the largest producer, the Alta, credited with an output of \$32,000,000, is inclosed in rocks of this kind. The favorable factor, however, in the formation of these deposits was certainly not the chemical character of the rock but its position with respect to the sources of mineralization.

GENERAL CHARACTER.

On the steeper declivities the andesites generally form bold outcrops, below which extend long talus slopes of angular fragments. In a broad way they are of similar appearance, fine grain, and dark color. Where, however, the latites prevail, the outcrops weather to a light gray or white, and the exposures resemble those of the rhyolites of the region. On examination at any one locality in detail, the andesites are found to comprise a considerable number of varieties. For example, the andesites at the mouth of the canyon of Tenmile Creek



A. STRATIFIED ANDESITE BRECCIAS FORMING SCARP ON CLIFF MOUNTAIN.



B. JOINTING IN GRANITE SOUTH OF BOULDER



show the following distinct varieties: (1) With numerous conspicuous feldspar phenocrysts; (2) with pyroxene phenocrysts alone prominent; (3) intermediate between (1) and (2); (4) amygdaloidal phases; (5) flow-banded phases; and (6) breccias, in which highly porphyritic fragments are inclosed in aphyric varieties; also other breccias, probably flow breccias in the main. On the summit of Thunderbolt Mountain thick sheets of lava, strikingly different in appearance, are found in superposition. One variety, a dark bluish black aphanitic rock, carrying small obscure phenocrysts of hornblende and plagioclase, is a fresh-looking lava and shows flow banding but only on the weathered surface. The adjoining lava sheet is of altered appearance and is a bluish-gray rock, carrying numerous conspicuous tabular plagioclase feldspars. It presents, therefore, a strong contrast to the former rock. Glassy porphyries also are prominently developed here.

These rocks are all of typical andesitic appearance. With them, however, are associated other varieties, which exhibit an obvious divergence from the andesitic type. These show small scattered phenocrysts of plagioclase and biotite in a groundmass of flinty texture and commonly display flow streaking. Conspicuously flow-banded varieties, nearly devoid of phenocrysts and of red flinty appearance, are found east of Boulder. North of Thunderbolt Mountain and west of Thunderbolt Creek these rocks, which chemical analysis shows to belong to the latite group, are present in great abundance. Flow banding and streaking is developed in these latites in an extraordinary degree, so that they rival in this respect the Tertiary rhyolites of the region.

PETROGRAPHY.

An andesite from the entrance of the canyon of Tenmile Creek is a dark heavy rock, in which the pyroxene phenocrysts are prominent because weathering in relief. In thin section it is found to contain numerous phenocrysts of calcic plagioclase, ranging up to $Ab_{30}An_{70}$, and of augite, which are surrounded by rims of brown-green amphibole. The groundmass consists of tabular plagioclase and granular amphibole, with some biotite and accessory magnetite bordered by titanite (?) rims. The rock has very probably been modified to some extent by contact metamorphism exerted by the near-by intrusion of quartz monzonite. It corresponds in appearance and mineralogy to the hornblende andesite porphyry, altered from an augite andesite and approaching a basalt in composition, from the southwestern part of the Elkhorn district, which has been described by Barrell and of which an analysis is available.¹

The bluish-black aphanitic andesite from Thunderbolt Mountain shows a porphyritic hyalopilitic texture. The andesite with the

¹ Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, p. 529.

prominent tabular feldspar crystals contains phenocrysts of plagioclase near Ab_1An_1 , and of chloritized and epidotized femic minerals in a cryptocrystalline matrix. Both are much poorer in femic minerals than the first-described andesite.

The latites are characterized by the occurrence of plagioclase and biotite phenocrysts in a cryptocrystalline groundmass of salic appearance. Blue, red, and flint-gray are common colors. Streakiness and flow banding are nearly universal.

A specimen from the top of the ridge on the west side of Thunderbolt Creek, near its head, is a porphyry carrying small vitreous plagioclase phenocrysts and bronzy plates of biotite embedded in a dark-red glassy groundmass of dull appearance. It displays a strongly marked eutaxitic structure, especially conspicuous on weathered surfaces, which are of light-gray color. Under the microscope the feldspars, which are well preserved, are found to be andesines near Ab_1An_1 , and the biotite plates to be chloritized. The groundmass is glassy, though partly devitrified; flow banding is finely developed, and swirls encircling the feldspars are common, together with a certain amount of breakage of the phenocrysts thus enveloped. Apatite and ilmenite, now altered to leucoxene, are present as accessory minerals.

Analysis of latite from Thunderbolt Creek, Mont.

[J. G. Fairchild, analyst.]

SiO ₂	64. 45	H ₂ O+.....	0. 80
Al ₂ O ₃	17. 69	TiO ₂.....	. 69
Fe ₂ O ₃	1. 33	CO ₂.....	. 29
FeO.....	1. 93	P ₂ O ₅.....	. 16
MgO.....	. 57	S.....	. 04
CaO.....	3. 73	MnO.....	. 05
Na ₂ O.....	3. 85	BaO.....	. 19
K ₂ O.....	3. 68		
H ₂ O-.....	. 59		100. 04

The low magnesia and the relatively high potash, together with the general andesitic composition, are noteworthy. The potash, which, as shown by the mineralogic make-up of the rock, is restricted largely to the groundmass, evidently caused the flowing lava to become stiff and viscous, so that most of these rocks show a highly flow-banded structure.

CONTACT-METAMORPHIC ALTERATION OF THE ANDESITES AND LATITES.

The andesites and latites in proximity to the quartz monzonite intrusion have undergone contact-metamorphic alteration. This has taken one of two forms, either simple recrystallization or recrystallization with addition of material. The former is the more common occurrence.

The contact-metamorphic alteration seems to be most apparent to the eye in the latites or andesites high in potash. Near the contact these rocks lose their dark color and become nearly white; the groundmass takes on obviously a microcrystalline character. Where the latites are flow banded this structure is retained, and the increased light color of the rocks enhances their resemblance to rhyolites. Under the microscope the main change is found to have taken place in the groundmass; whereas before metamorphism it was of cryptocrystalline texture, it is now a clear, well-individualized aggregate, consisting essentially of quartz and orthoclase, with biotite dispersed through it in small flakes. In places tourmaline appears as an accessory.

The most extensive metamorphism of the andesites has taken place on the north side of Elkhorn Peak, extending down to Prickly Pear Creek at 8,000 feet altitude. The rocks are mainly breccias and have been remarkably thoroughly recrystallized. The matrix of the breccias is commonly more coarsely crystalline than the included fragments, and in fact in many localities resembles a fine-grained diorite. The rocks are extensively injected with aplite dikes, many of which carry tourmaline, probably pyrogenetic, and are most thoroughly recrystallized where pierced by numerous aplitic dikelets. In the porphyries the augite phenocrysts have generally been converted to fibrous amphibole, which along with disseminated flakes of biotite, is also common in the groundmass.

The most notable pneumatolytic metamorphism observed in the region is that which has affected the thick stratum of andesitic breccia overlying the large limestone bed on the southwest flank of Elkhorn Peak. The breccia is composed of angular fragments of andesite, the largest 4 inches long; it has obviously been metamorphosed, showing patches of garnet and in places discrete areas composed solidly of fibrous tremolite, with fibers up to 2 inches in length. Thin sections cut from different places naturally show different textures and proportions of the component minerals. Garnet, pyroxene, scapolite, plagioclase, and accessory titanite and apatite, are the minerals present. Remnants of pyroclastic structure remain, as indicated by the presence of unobliterated porphyry fragments; plagioclase phenocrysts or pyroclastic fragments tend to remain intact, but as a rule the new growth of lime silicates has spread throughout the rock. The garnet is not grossularite, but very probably andradite, from the fact that its refractive index is near that of the minimum index of titanite intergrown with it. The pyroxene is a monoclinic variety, suggestive of hedenbergite in part. Scapolite occurs locally in broad plates poikilitically inclosing the other minerals. The plagioclase is mainly residual and is commonly scapolitized. All these features, together

with the macroscopic patches of fibrous tremolite, indicate that the breccia was originally calcareous, and was subsequently metamorphosed under the influence of chlorine-bearing solutions.

Northwest of Mullan Pass andesite sills lying between thick beds of coarsely garnetized sedimentary rocks are traversed by small veins carrying calcite and dodecahedral garnet.

AGE OF THE ANDESITES.

The age of the andesites is a matter of considerable interest, inasmuch as they are the youngest rocks into which the Boulder batholith is intrusive. Weed states that an Eocene age is indicated, but the evidence on which this is based is not given.¹ That they are certainly of pre-Oligocene age at least is proved by the fact that Oligocene sediments overlie them west of Cliff Mountain,² and at Pipestone Springs, near the southern border of the batholith.³

Southwest of Elliston the andesite breccias at the base of the andesite series were found interstratified with the sedimentary rocks, principally cross-bedded semiquartzitic sandstone, that overlie the fossiliferous strata of the marine Jurassic. A certain amount of conglomerate and limestone occurs with the sandstone, and the conglomerate contains some andesite fragments. These facts tend to show that the andesitic eruptions went on contemporaneously with the deposition of the late Mesozoic sediments. In the andesites occur thin intercalated beds of fossiliferous limestone, in appearance like those underlying the andesites. T. W. Stanton reports on the fossils:

7243. From a 7,000-foot mountain southwest of Elliston, Mont. This lot consists of drab fresh-water limestone containing poorly preserved undetermined ostracods and gastropods. The age is probably Cretaceous.

It is known that in eastern Montana volcanic activity commenced in the Montana epoch of the Cretaceous. Formerly it was believed that the eruptions began only after the Laramide orogenic revolution, but this has been disproved both by paleozoologic and paleobotanic evidence.⁴

It will therefore be held, pending the collection of more satisfactory material from the limestones interbedded with the andesites overlying the Boulder batholith, that the andesites are of late Cretaceous age.

The original thickness of the andesitic rocks is unknown. Southeast of Elkhorn, where they are regularly bedded and dip at a low

¹ Weed, W. H., *Geology and ore deposits of the Butte district, Montana*: Prof. Paper U. S. Geol. Survey No. 74, 1912, p. 29.

² Douglass, Earl, *Annals Carnegie Mus.*, Pittsburgh, vol. 5, 1909, p. 263.

³ Matthew, W. D., *Bull. Am. Mus. Nat. Hist.*, vol. 19, 1903, p. 197.

⁴ Stone, R. W., and Calvert, W. R., *Stratigraphic relations of the Livingstone formation of Montana*: *Econ. Geology*, vol. 6, 1910, pp. 551-557, 652-669, 741-764.

angle, a thickness of 2,000 feet is indicated,¹ but this figure is obviously a minimum estimate. The high ridges in which the andesites are exposed at Elkhorn have been carved from an area that has been subjected to prolonged and intense erosion ever since the beginning of the Tertiary period. During the same time other parts of the surrounding region, equally subjected to erosion, have been denuded of several thousand feet of rock covering, so that it is highly probable that the andesitic rocks had originally a far greater thickness.

QUARTZ MONZONITE.

GENERAL CHARACTER.

Granite is the predominant rock exposed throughout the region. It is, however, not a true granite, but is accurately designated a quartz monzonite. In local usage the term granite is employed universally and where adopted in this report it is employed in the popular sense. No true granite was found anywhere in the region; such modifications of the quartz monzonite as were noted are toward dioritic rocks.

The granite area of this region is the northern part of the great intrusive mass of granitic rock extending uninterruptedly from the Highland Mountains, 16 miles south of Butte, to Mullan Pass on the north. This large intrusion was named by Weed the Boulder batholith, from the name of the mountains throughout which it is exposed.² It occupies an area of about 1,100 square miles, extending 60 miles from north to south and averaging 18 miles in width.

In the mountainous areas the granite weathers in characteristic fashion, forming huge bowldery outcrops and making the country exceedingly rough and nearly impassable.

Locally the granite is traversed by pronounced systems of jointing, as at Rimini and also at Boulder (Pl. II, *B*, p. 24).

The granite has been quarried within the area considered in this report mainly at two points—on the Rimini road 8 miles west of Helena and at a locality north of Clancy. The stone from Clancy is used in the construction of the wings of the State capitol at Helena.

PETROGRAPHY.

The prevailing rock of the Boulder batholith is a coarse granitoid composed in the order named essentially of plagioclase, orthoclase, quartz, biotite, and hornblende. It is remarkably homogeneous in composition over a large area. A widespread feature, extending more or less persistently from Mullan Pass to Butte, is a rough porphyritic habit due to the development of large imperfect phenocrysts of orthoclase.

¹ Personal communication by R. W. Stone.

² Weed, W. H., *Granite rocks of Butte, Mont., and vicinity*: Jour. Geology, vol. 7, 1899, p. 737.

Toward the margins of the batholith the rock becomes somewhat finer grained and equigranular, as noted south of Helena, east of Boulder, and other localities. The rock apparently becomes more basic and the eye is at a loss to surely distinguish quartz monzonite from such modifications as granodiorite and quartz diorite. At certain localities, as verified by the microscope, the rock becomes dioritic in character.

A considerable number of chemical analyses of rock from widely separated localities on the northern part of the batholith are available, and emphasize the chemical homogeneity suggested by the mineral composition. Two of these analyses were made during the course of the present investigation; the others have been published by Weed.¹

Analyses of quartz monzonite from northern part of the Boulder batholith.

	1	2	3	4	5	6
SiO ₂	65.91	64.49	64.17	67.12	64.31	64.03
Al ₂ O ₃	15.32	15.49	15.25	15.00	15.44	15.58
Fe ₂ O ₃	2.28	1.19	2.16	1.62	2.43	1.96
FeO.....	2.02	2.71	2.98	2.23	2.58	2.83
MgO.....	1.52	1.89	2.60	1.74	2.21	2.15
CaO.....	3.28	4.32	4.24	3.43	4.22	4.20
Na ₂ O.....	3.08	3.53	2.62	2.76	2.71	2.76
K ₂ O.....	4.80	4.04	4.34	4.52	4.00	4.11
H ₂ O—.....	.60	.16	.16	.09	.19	.23
H ₂ O+.....	.60	.48	.65	.58	.79	.76
TiO ₂.....	.59	.56	.67	.48	.71	.59
P ₂ O ₅.....	.18	.19	.16	.14	.22	.18
MnO.....	Trace.	.07	.04	.06	Trace.	.11
SrO.....			Trace.	.03	Trace.	.04
BaO.....	.10	.06	.07	.07	.07	.07
Li ₂ O.....			Trace.		Trace.	
S.....	.02				Trace.	
SO ₂.....			.07	Trace.		
Cl.....			Trace.			
FeS ₂.....		.13				
	100.51	99.80	100.18	99.88	99.97	99.86

1. Valley Forge mine, Rimini. J. G. Fairchild, analyst.
2. King Solomon mine, Clancy. J. G. Fairchild, analyst.
3. Frohner mine. H. N. Stokes, analyst.
4. Boulder. H. N. Stokes, analyst.
5. Elkhorn. H. N. Stokes, analyst.
6. Butte, average of four closely similar analyses. H. N. Stokes, analyst.

The average analysis of the quartz monzonite at Butte has been added to show that it does not differ essentially from those of rocks from other parts of the batholith; it is, in fact, practically identical with that of the rock from Elkhorn, which lies on the eastern margin of the batholith, 33 miles northeast of Butte.

Under the microscope rock from different parts of the batholith shows broadly similar features. A zoned plagioclase near labradorite (Ab₅₀An₅₀) is found to be the dominant feldspar; the most calcic variety, from Elkhorn, as measured on the core is Ab₄₅An₅₅ and the least calcic Ab₅₉An₄₁—a remarkably narrow range in composition. Orthoclase and quartz are present in abundance and lie interstitially

¹ Op. cit., pp. 737-750.

between the idiomorphic plagioclase crystals. Biotite and hornblende are the ferromagnesian minerals, and the biotite commonly predominates. At Elkhorn a small amount of augite intergrown with the hornblende is found but none occurs elsewhere. The accessory minerals are magnetite, titanite, apatite, and zircon. The computed mineral composition of the quartz monzonite from Clancy (see p. 56) is 41.58 per cent plagioclase, 18.90 per cent orthoclase, 19.86 per cent quartz, 8.94 per cent biotite, and 7.26 per cent hornblende. At Elkhorn, according to Barrell,¹ it contains by volume 34 per cent labradorite, 22 per cent orthoclase, 25 per cent quartz, 7 per cent biotite, 9 per cent hornblende, and 2 per cent augite.

On Red Rock Creek and extending to Thunderbolt Mountain is a large body of gray diorite of medium grain. Rock from the mouth of the tunnel on the Calendar prospect under the microscope is seen to consist predominantly of plagioclase ($Ab_{55}An_{45}$), with interstitial quartz and orthoclase, each probably under 10 per cent in amount. Hornblende and biotite occur in minor quantities. Whether this diorite is a marginal phase or an earlier or later intrusion than the main batholith was not determined.

CONTACT METAMORPHISM.

The granite batholith and its outliers have invaded a great number of rocks of widely different character. The contact-metamorphic alteration produced by the invasion is correspondingly diverse from place to place, dependent on the original chemical composition of the rocks and on the local accession of material during metamorphism.

The simplest form of the contact metamorphism is the marmorization of the limestones in proximity to the granite contact. This is well shown south of Helena, where the Madison limestone has been coarsely recrystallized, so that it forms conspicuous snow-white outcrops. It is worthy of note that the basal member of the Madison limestone contains a multitude of minute tremolite and tourmaline needles, although the matrix inclosing them has not recrystallized. The tourmaline-tremolite content extends for over a mile from the visible contact. The content of tourmaline and tremolite differs in different beds; some contain much delicately fibrous or bladed tremolite and no tourmaline; others contain much tourmaline, and again others contain both minerals together. Tremolite, however, is by far the more abundant.

Along the contact south of Helena the rocks overlying the Quadrant quartzite have been extensively recrystallized, forming various kinds of biotite hornfels and micaceous quartzite. The metamorphism of the andesites has already been described on pages 26-28.

¹ Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, p. 538.

Garnetization has taken place on an extensive scale west and northwest of Mullan Pass at distances of over a mile from the exposed contact. Thick beds of solid garnet rock have been produced, the garnet crystals attaining a maximum diameter of 1 inch. Associated sills of andesite, as already pointed out, are traversed by veinlets carrying calcite and crystalline garnet.

At other localities in the region garnet and other silicate minerals traverse limestones in veins. They occur along the contact west of Nelson Gulch. Here the pure snow-white coarse marble is traversed by masses of lime-silicate minerals breaking across the bedding in

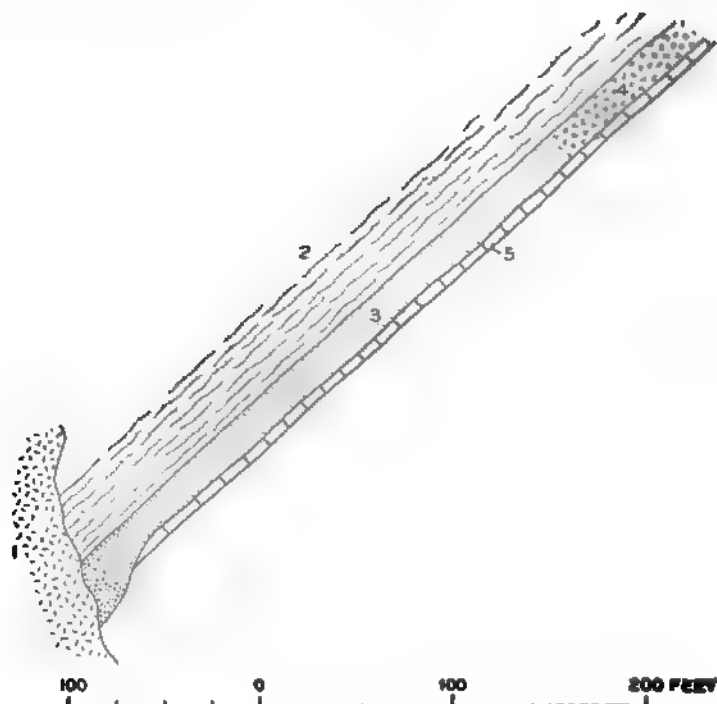


FIGURE 2 -Contact-altered rocks in Colorado Gulch. 1, Quartz monzonite; 2, biotitic quartzite; 3, garnet rock; 4, diopside hornstone; 5, marble stratum.

veinlike fashion. Similarly at the Spring Hill mine metamorphic minerals are developed locally and abruptly across the bedding of thinly stratified limestone.

These facts prove, without the necessity of chemical analyses, that an accession of material has taken place during contact metamorphism.

Near Colorado Gulch, west of Helena, contact-metamorphic rocks are exposed at the granite contact. Garnetization has proceeded continuously to a distance of 350 feet from the granite. At this distance the garnet rock merges into a series of thin-bedded dense diopside hornstones, aggregating 12 feet in thickness. The hornstones are inclosed between a footwall of black micaceous quartzite

and a hanging wall of coarse white marble 4 to 5 feet wide. The strike can readily be followed, as the marble on the hanging wall forms a continuous outcrop. Near the granite contact, as shown in figure 2, the garnetization has spread into the marble, forming a mass of brown garnet rock 25 feet thick. The portion of garnet rock that has replaced the limestone is irregularly filled with discontinuous veinlets or blebs of quartz holding large euhedral garnets. A small amount of galena and brilliant black sphalerite is intergrown with the garnet rock, but on the whole seems to favor the quartzose portions of the rock. Enough sulphides are present to have encouraged the prospector to sink an exploratory shaft.

Under the microscope the garnet rock is found to consist essentially of garnet, intergrown with small amounts of diopside, hornblende, calcite, and quartz. The cores of the garnet are generally isotropic, but the margins show zonal structure and optical anomalies. By the immersion method the index of the garnet is found to be 1.77, indicating a variety intermediate between grossularite and andradite. The hornstone into which the garnet rock grades along the strike is seen microscopically to consist of an intergrowth of a finely granular diopside and calcite, with accessory pyrrhotite.

Other examples of contact-metamorphic rocks that carry sulphides and oxides in quantities of economic importance are described under the contact-metamorphic ore bodies.

AGE OF THE QUARTZ MONZONITE.

The first description of the granitic rock from what is now known as the Boulder batholith is given by S. F. Emmons,¹ based on reports and specimens brought in by special agents of the Census. He recognized its unusual character and pointed out that it "proves to be a diorite of somewhat singular character, possessing certain marked characteristics." It was provisionally designated a diorite-granite and was thought to represent an eruptive body of Archean age.

Lindgren, who was a member of the Transcontinental Survey of 1883, termed this intrusive mass the Jefferson granite field, and regarded the great eruption as possibly of Jurassic age. He gave a brief petrographic description of the granite and recognized its resemblance to Zirkel's Jurassic granite from Nevada. The coal-bearing sediments resting on the eroded surface of the granite at Mullan Pass were believed to be probably of Laramie age.²

The later work on this problem has been done mainly by Weed, who assigned a post-Cretaceous age to the batholith in 1899.³ His final view is that the granite is Miocene in age.⁴

¹ Tenth Census, vol. 13, 1885, p. 95.

² *Idem*, vol. 15, 1886, p. 733.

³ Weed, W. H., *Granite rocks of Butte, Mont., and vicinity*: Jour. Geology, vol. 7, 1899, p. 737.

⁴ Weed, W. H., *Geology and ore deposits of the Butte district, Mont.*: Prof. Paper U. S. Geol. Survey No. 74, 1912, p. 29.

The evidence at hand is still not as complete or conclusive as is desirable. The youngest rocks into which the granite is intrusive are the andesites and latites, which, as shown earlier in this report, are probably of Cretaceous age and are definitely of later age than the Ellis formation. On the eroded surface of the granite west of Mullan Pass rests a series of unconsolidated lignite-bearing sediments, possibly of White River (lower Oligocene) age. At other localities in this part of Montana beds assigned by Douglass to the White River have been found by him to be slightly lignitiferous. If, as seems most probable, the rocks at Mullan Pass should prove to be the equivalents of either the Lance or the Fort Union, which are common coal-bearing formations in eastern Montana, the period of intrusion of the batholith would be certainly of pre-Tertiary age.

The Boulder batholith, covering an area of 1,100 square miles is in all probability an outlier of the far greater Idaho batholith, which is situated 150 miles to the west and covers an area of 20,000 square miles.¹ Between the two are many similar batholiths, such as those of the Philipsburg quadrangle. These have been found by F. C. Calkins² to cut rocks of Colorado (late Cretaceous) age. This fixes the inferior limit, but the superior limit in that area is not known. In view of the foregoing considerations it is concluded that the available evidence points to a late Cretaceous age for the Boulder batholith.

APLITE.

OCCURRENCE AND CHARACTER.

Aplite is a common rock within the area of the Boulder batholith and around its margin. It forms dikes and irregular masses, some of which are measured in square miles. The largest of these masses, east of Corbin, is shown on the geologic map (Pl. I), but other extensive areas of aplite were noted west of Jefferson and on the ridge south of Red Mountain. As estimated roughly, the aplite forms 5 per cent of the surface exposure of the batholith. Although aplite is so abundant, pegmatite is rare.

The border of the granite at many places is fringed with aplite, usually tourmaliniferous, which lies between the normal quartz monzonite and the invaded rock. Dikes of aplite also penetrate the rocks that inclose the batholith. They are particularly abundant near Wickes, where they occur as persistent dikes, up to 200 feet in thickness, traversing the andesites.

The aplites are fine-grained granular white rocks composed essentially of orthoclase and quartz, with minor amounts of biotite. Certain coarsely granular masses show a normal granitic texture and should be designated alaskite. Under the microscope the typical

¹ Umpheby, J. B., An old erosion surface in Idaho: Jour. Geology, vol. 20, 1912, p. 145.

² Personal communication.

aplites show a panidiomorphic aggregate of orthoclase, somewhat perthitic, and quartz, with subordinate plagioclase and biotite and accessory magnetite, titanite, and apatite. Two analyses of aplites from Elkhorn are available.

The aplites are commonly tourmaliniferous, but it is usually difficult to determine whether the tourmaline is an original constituent or was subsequently introduced. At a number of localities, however, the tourmaline seems to be clearly of pyrogenetic origin and not connected with fractures or jointing. South of Montana City there occurs a considerable body of aplite carrying nodules composed of tourmaline and quartz, which are scattered throughout the rock with some regularity. The nodules range from a fraction of an inch up to several inches in diameter, and from regular spheroids to most irregular blebs. The aplite is a snow-white rock, completely devoid of biotite, which as a rule is present to the extent of 1 or 2 per cent in the other aplites of the region. Under the microscope the aplite is seen to be of normal composition and texture; in the tourmaliniferous portion the tourmaline, which is an iron-rich variety, is intergrown in poikilitic fashion, mainly with quartz, but also with some orthoclase.

Similar tourmalinic nodules occur in the aplite at Elkhorn and have been described by Barrell.

ORIGIN OF THE APLITES.

Some aplites show intrusive contacts with the inclosing quartz monzonite, but others, especially those occurring along the borders of the batholith as marginal facies, show blended contact. The intrusive contacts, moreover, are welded and the aplite exhibits little evidence of chilling, so that it is clear that the aplite was intruded while the quartz monzonite was still hot.

Despite the great abundance of aplite in the region, there is a noteworthy scarcity of other satellitic intrusions, especially of lamprophyric or so-called complementary rocks, which are practically absent. This fact leads to the conclusion that the aplite was not derived from the splitting up of a single magma into two magmas, one salic and the other femic, but that it originated from the quartz monzonite magma by a process of fractionation during the cooling and consolidation of that magma. During this process tourmaline was concentrated in the aplite magma; by further segregation within the aplite magma the tourmaline formed the tourmaline-quartz nodules.

CENOZOIC ROCKS.

TERTIARY SEDIMENTARY ROCKS.

Stratified deposits which are here referred to the Tertiary period occur at three localities in the region—the Continental Divide west

of Mullan Pass, at Helena, and at Elliston. Those deposits exposed at Helena and Elliston belong to the so-called lake beds of western Montana.

The deposit near Mullan Pass consists mainly of clays and poorly indurated shales carrying some thin beds of low-grade lignite. Coarse conglomerate containing limestone and quartzite pebbles occurs, but as natural exposures are poor its relation to the rest of the deposit could not be determined. To the east the sedimentary rocks are apparently overlain by rhyolite. They rest on the eroded surface of the northern end of the Boulder batholith and contrast strongly with the thermally metamorphosed and garnetized older rocks surrounding them.

Some poorly preserved and indeterminable leaves were found near the coal exposures. These rocks were referred to the Laramie by Lindgren,¹ probably on the basis of their lignite content. Coal-bearing rocks of as late age as Fort Union (lower Eocene) having been formerly assigned to the Laramie, it is possible that the rocks at Mullan Pass are of Fort Union age. There is, moreover, a possibility that they may be even younger, inasmuch as Douglass has found beds of White River (lower Oligocene) age to be slightly lignitiferous, although this is uncommon in the so-called lake beds of western Montana.

The deposits near Helena consist of a bedded series of conglomerate, sands, clays, and tuffs, supposedly of Miocene age. West of Elliston is an extensive area of similar rocks, which according to Douglass are very probably of lower Oligocene age.² These beds are usually spoken of as lake beds. It is noteworthy that there are two very similar sets of lake beds in western Montana—one of lower Oligocene age and the other upper Miocene—lithologically alike and discriminable only by their mammalian fauna.

IGNEOUS ROCKS.

DACITES.

GENERAL CHARACTER AND DISTRIBUTION.

Dacites, consisting of a bedded succession of lavas, tuffs, and breccias, form a notable accumulation of volcanic rocks in the area immediately west of Wickes, and more especially in the area west of Basin. They are present here in great volume and extend southwestward to Butte, where they form Big Butte, from which that city takes its name. They occur also east of Silver City, in the northern part of the region considered in this report.

Although the dacites, when examined in detail, comprise a number of varieties, they display in general a remarkable uniformity.

¹ Tenth Census, vol. 15, 1886, p. 733.

² Douglass, Earl, Fossil Mammalia of the White River beds of Montana: Trans. Am. Philos. Soc., new ser. vol. 20, 1902, p. 244.

The commonest variety of dacite is a porous ash-gray rock carrying a multitude of plagioclase feldspar and quartz phenocrysts interspersed with small brilliant black flakes of biotite. The size and abundance of the feldspar and quartz phenocrysts is the characteristic feature of the dacites. The feldspars, many of which are an inch long, together with the quartzes make up, as a rule, half the bulk of the rock.

The dacites are unusually well exposed along the sides of Boulder Valley west of Bernice to the mouth of Lowland Creek. Tuffs exposed on both sides of the valley prove that the bedding is horizontal. This is the more noteworthy because the flow banding in the lava sheets is commonly vertical and certain lavas show a platy structure standing at a high angle. Swirl structures are common. Lava, otherwise massive, in places contains large irregular inclusions of breccia, which are enwreathed by a platy parting in the lava.

The section west of Bernice shows that here the dacitic rocks attained a thickness of at least 2,400 feet. The surface on which they were erupted was one of considerable relief carved in the granite and andesite. A section of this old surface is well exposed in a railroad cutting near the Great Northern tunnel, south of Wickes. Here at the base of the dacite series occurs a stratum of dacite tuff resting on an old stony soil derived from the underlying andesite. The surface is of moderate but irregular relief, and the tuff bed conforms completely to the underlying topography, proving that the tuff here is a wind-borne deposit. Locally, as near the Minah mine, conglomerate carrying well-rounded cobbles up to 12 inches long, some of them dacite but most of them andesite and aplite, is associated with tuff and lava sheets and doubtless indicates the operation of fluvial agencies during the eruption of the dacites.

Dikes of dacite traverse the quartz monzonite and the andesite-latite series. At some localities these dikes are remote from areas of the corresponding surface rocks. Because of their highly porphyritic character such dikes may easily be mistaken for granite porphyry or quartz diorite porphyry dikes. The porphyries that followed closely the great granite irruption, however, are far more granular than the dacites, and they do not resemble the dacites of the region, which have their own characteristic appearance. Certain of the dacite dikes have chilled margins showing a ropy structure, a feature which indicates intrusion comparatively near the surface.

PETROGRAPHY.

As already stated, the dacites are light-colored porphyries inclosing phenocrysts of plagioclase, quartz, and biotite embedded in an aphanitic groundmass. The feldspar is clear and glassy and is visibly striated, so that its plagioclase character is obvious to the eye. The

quartz is colorless, differing in this respect from the prevailingly smoky character of the quartz in the rhyolites of the region. It varies in amount in different rocks, being abundant in some and absent in others. Those devoid of quartz would be termed biotite andesites. Although such andesitic phases occur at a number of places, they are comparatively rare. Biotite is universally present, commonly as small thin hexagonal plates, but no other ferromagnesian mineral is found. Under the microscope the rocks, which are ideally fresh, are found to show essentially similar features in specimens from widely separated localities. The ratio of groundmass to phenocrysts approximates 1 to 1. The porphyritic feldspars are andesine, as a rule slightly more calcic than $Ab_{60}An_{40}$. Sanidine is absent from the phenocrysts, as shown by the Becke test on all unstriated feldspar sections. In one specimen only, from Sugarloaf Mountain (examined because of all the dacites it exhibits the nearest resemblance to the rhyolites of the region), were sanidine phenocrysts associated with the andesines. The quartz is generally much fractured and shows corrosion and embayment. Biotite is present in idiomorphic crystals and may be fluidally arranged around the plagioclase phenocrysts. The groundmass ranges in different specimens from glassy to microcrystalline. The microcrystalline form is best developed in those rocks occurring as dikes. Where the constituents of the groundmass are determinable, they appear to consist largely of sanidine and quartz. Apatite and zircon are present as accessory minerals, but magnetite is absent in all specimens examined.

According to the prevailing qualitative classification, the rocks are clearly biotite dacites. It has been pointed out by Rosenbusch¹ that the dacites fall into two rather distinct groups—the liparitic (rhyolitic) dacites and the andesitic dacites. Mineralogically and texturally the first group is closely related to the rhyolites and is characterized by the dominance of biotite and amphibole among the femic phenocrysts. The second is in an analogous way related to the andesites and is characterized by the dominance of pyroxene among the porphyritic minerals. The dacites of the region are rhyolitic in affinity. It is noteworthy perhaps that despite their great development biotite is uniformly the sole ferromagnesian mineral to appear as a porphyritic constituent. In the Butte folio these rocks at Butte were called rhyolites, but subsequently they have been termed rhyolite-dacites.² The rock at Big Butte is stated to grade from rhyolite through rhyolite-dacite to dacite. Apparently there is a greater mixture of varieties at Butte than there is farther north. The analysis cited is that of a typical dacite.³

¹ Rosenbusch, H., *Mikroskopische Physiographie der massigen Gesteine*, 4th ed., vol. 2, pt. 2, 1908, p. 999.

² Weed, W. H., *Geology and ore deposits of the Butte district, Mont.*: Prof. Paper U. S. Geol. Survey No. 74, 1912, p. 43.

³ *Idem*, p. 45.

AGE OF THE DACITES.

No evidence closely fixing the age of the dacites was found within the region. Their general Tertiary age is indicated by the fact that they rest on the deeply eroded surface of the Boulder batholith. Weed, however, has found that the eruptions were contemporaneous with the deposition of lake beds west of Butte. These are of upper Miocene age.¹

RHYOLITES.

GENERAL CHARACTER AND DISTRIBUTION.

A series of rhyolites rests on the eroded surface of the older rocks. Rhyolites are conspicuously developed near Rimini, where they form the capping of Red Mountain, whose commanding summit is a prominent landmark for many miles around. They crown the summits of many of the neighboring mountains and form the bedrock of the well-known "porphyry dike" country. They occur at Elliston, and on the Continental Divide north of Mullan Pass; they form small scattered patches east of Helena and occur in some abundance in the mountains east of Clancy.

The relief of the surface on which they were erupted has an extreme range of 3,600 feet—from an altitude of 7,600 feet on Red Mountain down to 4,000 feet in Prickly Pear Valley. At Rimini the relief was 2,000 feet in a horizontal distance of less than a mile. Thus it appears that the rhyolites were poured out on a surface as highly accidented as the present surface and whose configuration, as shown by the distribution of the rhyolites, was broadly similar to the existing topography.

The rhyolites are mainly lithoidal lava flows, but include some breccias and obsidians. They display a great variety of textures and colors, including grayish blue, red, pink, and white. Nearly universal features are pronounced streakiness and flow banding, abundant quartz phenocrysts, commonly smoky, and clear glassy sanidine phenocrysts. Dark minerals, such as biotite and hornblende, are not present in most of the rhyolites; some few show a scattering development of biotite. Lithophysæ occur locally in notable abundance and perfection.

A platy or laminated structure parallel to the flow banding is common, causing the rhyolites to break in thin slabs. In places, as west of Elliston and on Minnehaha Creek near Rimini, there is a pronounced columnar structure. The columns are irregular four and five sided prisms up to 6 feet in length. Single columns may show different sets of flow bands, making widely different angles with the same prism edge, a feature proving conclusively that the flow banding is no criterion of the original attitude of the surface on which the

¹ Weed, W. H., op. cit., p. 46.

rhyolites were extruded. In fact, flowage lamination standing at angles ranging from 0° to 90° was found at various places throughout the region.

The thickness of the rhyolite series is not well known, because the bedding or order of superposition of the lava flows is not easily recognizable. On Red Mountain they aggregate at least 600 feet and may be as much as 1,200 feet.

The rhyolite series consists of rhyolites only; neither dacites, quartz latites, nor other transitional rocks are associated with them. They differ notably in appearance from the dacites of the region, which are of general rhyolitic habit, and in fact have been termed rhyolites at Butte. They lack the extraordinarily prominent porphyritic development of the dacites, which is expressed by the abundance of unusually large phenocrysts of quartz and plagioclase. They lack also the biotite, so common in the dacites. Lithophysæ, smoky quartz crystals, and streakiness are restricted to the rhyolites. There is some possibility that the far older latites, which are light colored and show pronounced streakiness, especially those in the country north of Thunderbolt Mountain and at the headwaters of Little Blackfoot River, may be mistaken for rhyolites. However, the latites show no quartz phenocrysts nor do they have the fresh, unaltered appearance that characterizes the rhyolites. West of Elliston some black glistening basalt carrying large amber-colored phenocrysts of plagioclase is found, and this is one of the few exceptions to the rule that the rhyolite series is free from rocks of other types.

PETROGRAPHY.

The rhyolites are light-colored porphyries carrying phenocrysts of quartz and sanidine. The quartz phenocrysts average one-tenth of an inch in length and the sanidine phenocrysts are perhaps twice that size; together they make up between 10 and 20 per cent of the rock. The groundmass of the lithoidal rhyolites ranges from material of rough fracture to that of enamel-like appearance.

Under the microscope the phenocrysts are found to consist of corroded and embayed quartz and idiomorphic sanidine crystals; no plagioclase phenocrysts have been detected. The groundmass commonly shows a microcrystalline development; flow streaking is generally present.

A chemical analysis of a rhyolite from the summit of Red Mountain near Rimini is available¹ and is doubtless typical of the rhyolites generally. This rhyolite shows numerous dark smoky quartz and

¹ Cited by F. W. Clarke in Analyses of rocks and minerals from the laboratory of the United States Geological Survey, 1880-1908: Bull. U. S. Geol. Survey No. 419, 1910, p. 80; the rock has not hitherto been described.

clear vitreous sanidine phenocrysts inclosed in a groundmass remarkably mottled and streaked. The general color of the rock is gray, diversified by mottlings and bands of various colors, among which dark red is especially prominent. Along some of the flow bands the rock is porous. Microscopically the quartz phenocrysts are seen to be corroded and embayed, whereas the sanidine crystals are comparatively intact. Some of the crystals show that they were broken by flowage movement with the cooling lava. Many of the quartz crystals are surrounded in optical continuity by aureoles of quartz inclosing feldspar. The quartz crystals are commonly much cracked. The sanidine phenocrysts are beautifully clear and fresh; optical tests show that they are nearly uniaxial. The groundmass is holocrystalline and eutaxitic, and in places is considerably pigmented with hydrated iron oxide, which is in part a later infiltration along the flow bands. Mineralogically the groundmass consists of feldspar and quartz; the fabric is different in different flow streaks but is commonly microgranitic and micropoikilitic, with sporadic spherulitic growths. Doubtless the groundmass contains much albite, but it can not be easily differentiated. Zircon is present as a rare accessory.

Analysis of rhyolite from top of Red Mountain, Rimini.

[H. N. Stokes, analyst.]

SiO ₂	75.30	H ₂ O above 110°.....	0.61
Al ₂ O ₃	11.95	TiO ₂.....	.17
Fe ₂ O ₃	} 2.17	P ₂ O ₅ , MnO, BaO, Li ₂ O, Cl.....	Trace.
FeO.....		SrO, CO ₂	None.
MgO.....	.05	SO ₃.....	.44
CaO.....	.62	Organic matter.....	.45
Na ₂ O.....	3.09		<hr/>
K ₂ O.....	4.96		100.17
H ₂ O at 110°.....	.36		

AGE OF THE RHYOLITES.

The rhyolite series seems, because of its general petrographic homogeneity, to represent an outburst of volcanic activity distinct from that of the dacitic eruptions which are known to have taken place in upper Miocene time. However, as the rhyolites have not been found in contact with the dacites, their relation to the dacites is not known. If they were not contemporaneous with the dacites, they probably represent a somewhat younger period of volcanism, as they were erupted upon a surface broadly similar to that of the present.

QUATERNARY SYSTEM.

The Quaternary deposits consist of alluvial gravels, sands, and silts. Patches of high bench gravels occur at many localities, but on

account of their small size are not shown on the map (Pl. I). Glacial deposits were noted at Elkhorn, at Red Rock Creek, and on Little Blackfoot River, but because they are of small extent and no special study of them was made they have also not been differentiated.

THE ORE BODIES.

GENERAL CHARACTER.

The ore bodies of the region, classified according to metallic contents, are principally silver-lead and gold-silver deposits. These two classes include practically all the productive deposits of any importance, both past or present.

The silver-lead ore body of the Alta mine, having an accredited output of \$32,000,000, has been the largest producer; next in order comes the Drumlummon, the premier gold-silver mine, with an output of \$15,000,000.

The deposits, classified according to age of origin, fall into two distinct groups formed during widely separated periods of mineralization. Both groups, based on this age distinction, include silver-lead and gold-silver ores, but heavy lead ores are not common in the lodes of the younger set, which are mainly valuable for their content of the precious metals.

The older group of metalliferous deposits was formed subsequent to the intrusion of the Boulder batholith and prior to the eruption of the rhyolitic and dacitic lavas; the younger group was formed after the extrusion of the volcanic rocks. The older deposits are probably of late Cretaceous or early Eocene age, and the younger are surely of post-Miocene age. A number of the older deposits have been shattered and broken and subsequently recemented by quartz of the second period of mineralization, so that composite ore bodies were produced. Whether any important addition to the metallic contents of the older deposits accompanied the new mineralization could not be determined.

That a long period of time intervened between the formation of the older and the younger deposits is indicated by the geologic history of the region. The rocks covering the granite were largely removed by erosion, the granite was deeply dissected to an uneven surface, and on this surface there was erupted a considerable mass of volcanic rocks—dacitic lavas, tuffs, and breccias—to the thickness, locally at least, of 2,400 feet. Following this volcanic outburst came the second period of mineralization.

Primary minerals of the ore deposits.

	Earlier de- posits (Cre- taceous).	Later de- posits (post- Miocene).	Doubtful.
Adularia.....		X	
Andradite.....	X		
Apatite.....	X		
Aragonite.....	X		
Argentite.....		X	
Arsenopyrite.....	X		
Axinite.....	X		
Bismuthinite.....	X		
Bernite.....			X
Calcite.....	X	X	
Cassiterite.....			X
Chalcedony.....		X	
Chalcopyrite.....	X	X	
Chlorite.....		X	
Cosalite.....	X		
Dolomite.....	X	X	
Epidote.....	X		
Fluorite.....			X
Galena.....	X	X	
Garnet.....	X		
Gold.....	X	X	
Hematite.....	X		
Magnetite.....	X		
Molybdenite.....	X	X	
Opal.....		X	
Pyrite.....	X	X	
Pyroxene.....	X		
Pyrrhotite.....	X		
Quartz.....	X	X	
Rhodochrosite.....			X
Sericite.....	X	X	
Siderite.....		X	
Sphalerite.....	X	X	
Tetradymite.....	X		
Tetrahedrite.....	X	X	
Tourmaline.....	X		

According to the classification of Lindgren,¹ it will be seen that many minerals of the earlier group are characteristic of ore deposits formed under deep-seated conditions, whereas those of the later group belong to those of shallow-zone origin.

OLDER ORE DEPOSITS (LATE CRETACEOUS?).

CLASSIFICATION.

The ore deposits of the first period of mineralization are mainly silver-lead lodes, but include some gold and some copper deposits. They are here classified on a genetic basis, although this has certain practical disadvantages. They are grouped as (1) magmatic deposits, (2) contact-metamorphic deposits, and (3) lodes and veins.

The third group embraces most of the ore bodies of the region. This group may be further subdivided on the basis of the predominant metasomatic process, in accordance with the classification of Lindgren, as tourmalinic lodes and sericitic lodes. The separation of the tourmalinic from the sericitic lodes is somewhat arbitrary, inasmuch

¹ Lindgren, Waldemar, The relation of ore deposition to physical condition: Econ. Geology, vol. 2, 1907, p. 122.

as the tourmalinic lodes are also sericitic and transitional forms occur from highly tourmalinic to nontourmalinic. This subdivision has the disadvantage of separating into different groups ore bodies having similar metallic contents. In the following pages, therefore, the sericitic veins are not accorded extended treatment, because the evidence seems clear that they represent a slightly less energetic phase of the tourmalinic mineralization.

MAGMATIC DEPOSITS.

The single representative of this class found within the region is in the Golden Curry mine at Elkhorn. The ore body, consisting of an intergrowth of pyrrhotite and chalcopyrite with augite, is inclosed in quartz monzonite and represents a local differentiation and segregation in the magma.

CONTACT-METAMORPHIC DEPOSITS.

A number of contact-metamorphic deposits occur throughout the region but as a rule are of small economic importance. They are invariably situated near the contact of limestone with quartz monzonite or a related granitic rock. They consist of a simultaneous intergrowth of the ore minerals with various silicates, among which an iron-bearing garnet, probably andradite, is usually present. In some ore bodies, however, the generation of the ore minerals seems to have persisted somewhat longer than that of the silicate minerals. Deposits valuable for gold, for copper, and for iron have been found.

The largest ore body of this type is the auriferous deposit of the Spring Hill mine, near Helena, which has been worked on an extensive scale. This deposit lies at the contact of a small mass of diorite intrusive into the Madison limestone. The ore minerals are pyrite and pyrrhotite; in places the pyrrhotite forms solid masses several feet in length and width. They are usually associated with a fine-grained aggregate of lime-silicate minerals, forming an exceedingly hard and tough rock, but are also disseminated in grains and blebs through the pure limestone.

Another auriferous deposit of contact-metamorphic origin is the Dolcoath ore stratum at Elkhorn, carrying telluride and sulphide of bismuth and chalcopyrite intergrown with an iron-bearing garnet, diopside, and calcite.

Contact-metamorphic copper ore has been exploited to some extent near Elliston, where an oxidized copper ore intergrown with garnet and calcite was mined.

Bodies of magnetite ore, associated with andradite and lesser amounts of axinite, have been mined as fluxing material at Elkhorn; they carry also minor quantities of copper and gold.

An aberrant type of ore deposit is represented by the Blue Bell mine, near Mullan Pass. This deposit consists of a lode of garnet rock traversing the monzonite and carrying locally chalcopyrite, molybdenite, and pyrite. The contact of the garnet rock with the inclosing monzonite is blurred and shows gradual transition from garnet rock to monzonite. Branch veinlets of garnet break off at right angles to the larger veins. The adjoining monzonite shows unusual metasomatic alteration, apparent even macroscopically. When examined microscopically the most intensely altered monzonite is found to consist of scapolite in broad plates poikilitically inclosing garnet. Other details are given under Elliston.

The deposit is in many respects analogous to that at Mackay, Idaho, described by Kemp,¹ which consists of pipes of cupriferous garnet rock inclosed in quartz porphyry. Whatever explanation is adopted for the Blue Bell deposit, at least the conclusion is incontrovertible that the garnet molecule was able to migrate and form vein-like deposits under the influence of solutions that carried chlorine, as shown by the accompanying scapolitization.

TOURMALINIC LODES.

VARIETIES OF ORES.

A striking feature of many of the ore deposits of the earlier group is their abundant content of tourmaline. This mineral, as is well known, is of comparatively rare occurrence in ore deposits other than tin lodes. It is found associated, to some extent, with gold ores at various localities and with gold-copper ore, notably in Chile. It is therefore a matter of considerable interest that tourmaline is a common gangue and metasomatic mineral in the ores of this region.

The ores include varieties differing widely in mineralogic character and metallic content. On this basis three types can be distinguished—(1) tourmalinic silver-lead; (2) tourmalinic silver-copper; (3) tourmalinic gold.

In connection with the prevalence of tourmaliniferous ore deposits in the region it is worthy of note that cassiterite was frequently found in the gold placers in early days—in Tenmile Creek, in Prickly Pear, and in many others. It has nowhere yet been found in its bedrock source. The cassiterite was commonly in the form of wood tin, a form recognized by German authors as of secondary origin. It is probable therefore that the cassiterite was derived from the erosion of the oxidized croppings of lodes carrying slightly stanniferous sulphides.

¹ Kemp, J. F., The White Knob copper deposits, Mackay, Idaho: Trans. Am. Inst. Min. Eng., vol. 38, 1907, pp. 269-296.

TOURMALINIC SILVER-LEAD DEPOSITS.

DESCRIPTION.

The silver-lead deposits are the most important group of the tourmalinic lodes; they have given rise to the largest number of mines and have yielded the greatest metallic output. This is the more noteworthy in that they constitute a group of ore deposits that is unique so far as shown by the literature of economic geology.

They are developed most strikingly at Rimini, where tourmaline forms the dominant metasomatic mineral of the ore at certain mines, notably the Lee Mountain and the Valley Forge. At Wickes the Alta lode, which has been by far the most productive ore body in the region, shows pronounced tourmalinization. Other lodes in the Wickes district, such as the Comet and Gregory, are probably end members of the same type of deposit, but in which the tourmalinization was feeble. Finally, the tourmalinic silver-lead type is represented at Elkhorn by the Queen mine.

The deposits at Rimini afforded a better opportunity for examination than those at other localities, so their characteristics will be presented in some detail.

The lodes are inclosed in quartz monzonite of uniform composition, which is quite similar to that prevailing throughout the Boulder batholith. A pronounced system of jointing that trends N. 85° E. and dips 80° S. traverses the quartz monzonite. The joints as a rule are widely spaced and are remarkably plane and parallel. Locally they are closely spaced, as at the falls of Beaver Creek, above the town of Rimini, and the joint faces are coated black with a thin felt of tourmaline fibers.

The ore bodies conform in direction to this system of jointing. The ore occurs in chambers or shoots scattered through a zone which in a few places attains an extreme width of 50 feet. In this zone the granite is profoundly altered by sericitization and is strongly impregnated with metallic sulphides. Commercial ore consists of a heavy sulphide aggregate, composed principally of galena associated with sphalerite and pyrite. Arsenopyrite in small amount is a ubiquitous constituent; tetrahedrite and chalcopyrite occur rarely. The ore is more or less mixed with metasomatically altered granite, but not with vein quartz or other gangue material common in fissure-filled veins.

The ores carry approximately 2 ounces of silver to each 1 per cent of lead, and gold running as high as \$11 a ton in high-grade ore.

The characteristic feature that distinguishes these deposits from the usual types of ore body is that they are accompanied along one wall or the other by what is termed locally a ledge of black quartz. This ledge consists of a coal-black rock composed essentially of an intergrowth of quartz and black tourmaline. In places the grain is

so dense that the tourmaline is not discriminable and the rock resembles a black jasperoid; in other places the grain is coarser and the radial fibrous structure of the tourmaline is readily apparent. Another phase of the tourmalinic rock shows a mottling due to small patches of vitreous quartz, and is perhaps of interest because of its resemblance to the so-called capel accompanying the cassiterite lodes of Cornwall, as determined by direct comparison with a specimen of capel—a quartz-tourmaline rock—from the 2,800-foot level of the Dolcoath mine.

In places the quartz-tourmaline rock is roughly banded, owing to the presence of intercalated slabs of sericitized granite. This banded phase indicates clearly how the tourmalinic ledge originated. The black tourmalinic bands merge, by diminution in the amount of tourmaline, into sericitized granite. The tourmalinization evidently proceeded from joint planes in the granite; where the jointing was closely spaced or the tourmalinization was intense the granite was altered completely and solidly to a quartz-tourmaline rock. In this way black tourmalinic ledges were formed, extremely dissimilar to the granite from which they were derived, and attained a maximum thickness, so far as observed, of 8 feet. It is noteworthy that the most productive lodes are accompanied by the thickest ledges, although, on the other hand, ore does not occur continuously along these ledges. The tourmalinic rock carries a varied amount of metallic sulphides, among which arsenopyrite predominates, accompanied by pyrite, sphalerite, and galena. Locally it is brecciated and traversed by thin veinlets of quartz and arsenopyrite.

Black jasperoidal tourmaline rock from the Valley Forge mine, as shown by microscopic examination, is composed of quartz and tourmaline in approximately equal amounts. The tourmaline is a brown variety, and is present in granular, columnar, and acicular forms. Other minerals are arsenopyrite, pyrite, sphalerite, galena, sericite, and apatite.

The manner in which the tourmalinization proceeded is clearly indicated in an open cut on the probable eastern extension of the Lee Mountain lode, in the town of Rimini. A sketch of this is given in figure 3. Twenty feet west of the open cut a prospect shaft encountered some heavy galena ore on this tourmalinized zone.

The ore bodies occur in shoots alongside the tourmalinic ledge matter. There is, however, complete though abrupt gradation between the tourmaline rock and the ore material. The ore favors the sericitically altered granite. A certain definite tendency of the sulphides to segregate during deposition is therefore evident, galena-rich ore tending to develop most abundantly in the sericitic phase of alteration. That the development of the sulphides and the tourmalinization were contemporaneous is proved by the intergrowth of

the sulphides with the tourmaline. Another line of evidence is the fact that the granite, where traversed by quartz-tourmaline veinlets devoid of metallic sulphides, is tourmalinized, sericitized, and impregnated with arsenopyrite, pyrite, sphalerite, and galena. This indicates beyond question that the same solutions that carried the tourmaline-producing elements carried also the metallic sulphides; it indicates further that there was probably a tendency of the tourmaline to develop slightly ahead of the sulphides.

CHEMICAL PROCESSES.

The chemical processes accompanying the formation of the tourmalinic silver-lead deposits were investigated by a series of analyses of rocks from the Valley Forge mine at Rimini.

The normal country rock, taken at 30 feet from the footwall of the lode at the portal of the main tunnel, is a comparatively fresh quartz monzonite composed of zoned plagioclase near $Ab_{51}An_{49}$, orthoclase,

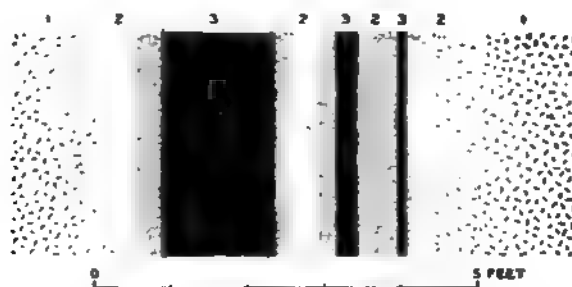


FIGURE 3. Tourmalinized zone in granite Rimini. 1, quartz monzonite; 2, pyritized and sericitized quartz monzonite; 3, black tourmaline-quartz rock.

quartz, micropegmatite, biotite, and hornblende, with accessory magnetite, titanite, apatite, and zircon. Sericite, chlorite, and iron oxide occur in small amounts as secondary minerals. Altered quartz monzonite, taken from rock adjoining the quartz-tourmaline ledge on the hanging wall and selected so as to contain a minimum of tourmaline, is a coarse quartzose rock containing considerable glossy sericite in fine scales and pyrite in deeply striated cubes. Arsenopyrite, sphalerite, and galena are present in lesser quantities. Under the microscope quartz in large optically homogeneous anhedrons is seen to be the dominant constituent; sericite and sulphides are common. A deep-brown iron-rich variety of tourmaline is present in small amount. Arsenopyrite is as a rule sharply crystalline; pyrite is also well crystallized, but the galena and sphalerite are anhedral. Apatite and zircon appear as accessory minerals.

Rock taken from the footwall, and therefore several feet from the tourmalinic ledge, consists of highly sericitized quartz monzonite impregnated with pyrite, galena, arsenopyrite, and sphalerite. The

sericite forms translucent waxy patches of light yellowish-green color. The microscope shows that the component minerals are, in order of abundance, quartz, sericite, pyrite, galena, arsenopyrite, and sphalerite and accessory rutile, apatite, and zircon.

Analyses of fresh and altered wall rocks, from Rimini, Mont., and St. Michaels Mount, Cornwall.

	1	2	3	4
SiO ₂	65.91	66.70	66.02	69.42
Al ₂ O ₃	15.32	13.25	14.14	15.65
Fe ₂ O ₃	2.28	1.34	1.53	1.25
FeO.....	2.02	.51	.37	3.30
MgO.....	1.52	.30	.67	1.02
CaO.....	3.28	.05	.26	.63
Na ₂ O.....	3.08	.39	.39	.27
K ₂ O.....	4.80	4.03	4.63	4.06
H ₂ O—.....	.60	.08	.10	.06
H ₂ O+.....	.60	.37	.48	.54
TiO ₂.....	.59	.20	.56	Trace.
CO ₂.....	.21	.21	.25	.....
P ₂ O ₅.....	.18	.12	.17	.40
MnO.....	Trace.	Trace.	Trace.	.39
BaO.....	.10	None.	.04	.....
Li ₂ O.....	.....	.....	.....	.81
B ₂ O ₃.....	.....	.....	.....	.59
F.....	.....	.....	.02	3.36
PbS.....	.....	.50	2.02	.....
ZnS.....	.....	1.86	.74	.....
FeAsS.....	.....	5.09	.72	.....
FeS ₂.....	.....	4.75	6.73	.....
Less O for F.....	100.51	99.84	99.84	101.75
				1.41
				100.34
Specific gravity.....	2.651	.....	2.893	.....

- 1. Quartz monzonite, fresh, from Rimini, Mont. J. G. Fairchild, analyst.
- 2. Quartz monzonite, altered, from hanging wall, Valley Forge mine, Rimini, Mont. J. G. Fairchild, analyst.
- 3. Quartz monzonite, altered, from footwall, Valley Forge mine, Rimini, Mont. J. G. Fairchild, analyst.
- 4. Greisen (with tourmaline and topaz), from St. Michaels Mount, Cornwall. W. Pollard, analyst.

It is apparent from the analyses that the course of alteration has been essentially similar in both wall rocks: perhaps the fact is noteworthy, however, that the high arsenopyrite and low galena go with the tourmaliniferous phase of alteration. The pronounced removal of all bases other than potash and the low combined water—lower than in the unaltered rock—are striking features. The potash is all present in sericite, but the amount of water is far too low to compute the sericite as K₂O.2H₂O.3Al₂O₃.6SiO₂, the formula usually employed. In this respect the alteration of these wall rocks departs from that of most sericitized wall rocks, it being the general experience that water is commonly in excess of the amount required by the formula K₂O.2H₂O.3Al₂O₃.6SiO₂. For purposes of comparison an analysis of a greisen from Cornwall has been added, which shows a similar deficiency of water with regard to the content of potash.¹ But such examples are rare.

¹ Reid, Clement, and Flett, J. S., Geology of the Land's End district: Mem. Geol. Survey England and Wales, 1907, p. 59.

To trace the course of alteration more closely the following computations have been made, based upon the assumption of constant volume. They bring out clearly that the net increase of mass, amounting to 9 per cent, has been due chiefly to the introduction of the metallic sulphides; that there has been a notable gain in iron (as pyrite and arsenopyrite), sulphur, lead, arsenic, zinc, and silica; and that there has been a heavy loss in all bases except potash, which has remained practically unchanged in amount.

Alteration of quartz monzonite from Rimini, Mont.

	1	2	1a	2a	3	4	5
SiO ₂	65.91	66.02	174.80	191.00	+16.2	+ 9.28	+6.12
Al ₂ O ₃	15.32	14.14	40.60	40.90	+ .3	+ .74	+ .10
Fe ₂ O ₃	2.28	1.53	6.05	4.43	- 1.62	-26.8	- .61
FeO.....	2.02	.37	5.36	1.07	- 4.29	-80.1	-1.62
MgO.....	1.52	.67	4.03	1.94	- 2.09	-51.9	- .79
CaO.....	3.28	.26	8.70	.75	- 7.95	-90.4	-3.00
Na ₂ O.....	3.08	.39	8.17	1.13	- 7.04	-86.2	-2.65
K ₂ O.....	4.80	4.63	12.72	13.38	+ .66	+ 5.19	+ .20
H ₂ O-.....	.60	.10	.....	.....	.....	.....	.....
H ₂ O+.....	.60	.48	1.50	1.39	- .20	.....	.....
TiO ₂.....	.59	.56	1.56	1.62	+ .06	.....	.....
CO ₂.....	.21	.25	.56	.72	+ .16	.....	.....
P ₂ O ₅.....	.18	.17	.48	.49	+ .01	.....	.....
BaO.....	.10	.04	.26	.12	- .14	.....	.....
PbS.....	.....	2.02	.....	5.84	.....	.....	+2.20
ZnS.....	.....	.74	.....	2.14	.....	.....	+ .81
FeAsS.....	.....	.72	.....	2.08	.....	.....	+ .78
FeS ₂.....	.....	6.73	.....	19.45	.....	.....	+7.33
	100.51	99.82	264.88	288.45	.....	.....	+8.87
Specific gravity.....	2.651	2.893	.....	.....	.....	.....	.....

- 1. Chemical composition of unaltered quartz monzonite.
- 2. Chemical composition of altered quartz monzonite.
- 1a. Constituents in grams of 100 cubic centimeters of unaltered rock.
- 2a. Constituents in grams of 100 cubic centimeters of altered rock.
- 3. Gain or loss in grams of each constituent during alteration.
- 4. Gain or loss in percentage of original mass of each constituent.
- 5. Gain or loss in percentage of original mass of the unaltered rock.

TOURMALINIC SILVER-COPPER DEPOSITS.

The principal representative of the tourmalinic silver-copper type is the Blue Bird mine in the Wickes district. The ore at this mine consists essentially of tetrahedrite and pyrite intergrown with tourmaline. Sphalerite and galena are rare constituents. The ore contains from 10 to 25 ounces of silver, 3 to 5 per cent of copper, and small amounts of gold.

Pockets of ore, composed of columnar arsenopyrite in a matrix of sphalerite and pyrite and carrying 2 ounces of gold to the ton, have been found in highly tourmalinized diorite porphyry near the lode. A shoot of ore formerly worked carried 0.56 ounce of gold and 65 ounces silver a ton, but it probably contained more galena and arsenopyrite than the ore now being extracted, which is an argenterous tetrahedrite intergrown with tourmaline.

The bearing of these facts is that the tourmalinic silver-copper type of deposit is very probably connected by transitions with the

other types of tourmalinic lodes of the region. That the tourmalinic silver-copper deposit of the Blue Bird mine differs from previously described tourmalinic ore bodies, notably from the tourmalinic gold-copper type, has recently been pointed out by the Winchells.¹

Tourmalinic ore bodies, such as the Eva May and the Bullion, which carry pyrite, tetrahedrite, galena, sphalerite, chalcopyrite, and arsenopyrite in variable amounts and are both argentiferous and auriferous, form transitions between all three types of tourmalinic deposits recognized in the region.

TOURMALINIC GOLD DEPOSITS.

The only tourmalinic deposit valuable solely for its gold content is the Big Indian, situated in Jefferson County, 4 miles south of Helena. Most of the other tourmalinic deposits, however, are auriferous to some extent, and in many the gold is an important constituent. In the Evening Star ore, a tourmalinic gold-silver-lead ore, the gold is stated to have run as high as 3 ounces to the ton.

The Big Indian mine is situated in the quartz monzonite one-half mile from the intrusive contact with the sedimentary rocks lying to the north. The ore was taken out from a large pit. In the bottom of this pit it can be seen that the quartz monzonite is in places extremely sheeted by a system of vertical joint cracks. These sheeted zones were loci of tourmalinization and pyritization, and probably of auriferous impregnation. The tourmalinized rock is a medium-grained gray granitoid, which contains about as much tourmaline as the unaltered rock contains ferromagnesian minerals—approximately 10 per cent. The tourmaline aggregates are somewhat porous and contain some yellowish material of undetermined character. Under the microscope the rock is found to consist of plagioclase, orthoclase, micropegmatite, tourmaline in irregular granular aggregates, brown mica in fan-shaped groups, magnetite apparently in part epigenetic, titanite, and apatite.

According to Mr. James Winscott, the discoverer of the deposit, approximately \$110,000 in gold was extracted during five years' operations of the old 10-stamp mill formerly on the property. The ore averaged \$5 a ton and some clean-ups ran 985 fine. Subsequently the property was sold and a 60-stamp mill was erected, but this is now idle.

ORIGIN OF THE OLDER ORE DEPOSITS.

The ore deposits of the first period of mineralization are closely related to the intrusion of the quartz monzonite, as shown by three features: (1) Their geologic environment, namely, their restriction

¹ Winchell, H. V. and A. N., Notes on the Blue Bird mine: Econ. Geology, vol. 7, 1912, p. 289.

to the vicinity of intrusive contacts of the quartz monzonite; (2) their mineralogy; and (3) the fact that a number of them are cut by Tertiary dacite dikes.

They occur either at the margins of the batholith or in remnants of the roof under which the quartz monzonite was intruded. The largest fragment of the roof that has escaped the erosion and general removal of the rocks formerly covering the batholith—the large remnant of the andesitic roof west of Wickes—has been the great treasure vault of the region. The most productive mines, to name only the Alta, Comet, Gregory, and Minah, were grouped in this fragment of the roof or along its margin.

This geographic restriction of the ore bodies to the intrusive contacts is not of itself conclusive proof that the deposits are genetically related to the intrusion of the quartz monzonite. This is illustrated by the Marysville district, where a series of lodes is massed along the periphery of a boss of quartz diorite but is not connected in origin with the intrusion of the plutonic rock. It is obviously of more importance to show that a close sequence in time exists between intrusion and metallization, but that such a sequence exists can be shown in the broadest sort of a way only. After the granite had consolidated to a considerable depth it was fractured; the ore deposits were formed; subsequently the covering rocks, of unknown thickness, were stripped off and the granite was deeply eroded; and finally in upper Miocene time the dacite lavas were erupted on this surface.

The geographic restriction of the ore deposits considered in connection with their mineralogy is, however, conclusive proof of their genetic dependence on the quartz monzonite intrusion. The third criterion, the intersection of an ore deposit by dacite dikes, is not of great moment, but it establishes the fact that ore deposits so intersected were formed prior to the second period of mineralization.

The ore deposits, as shown by their abundant content of tourmaline, were formed at a high temperature—a condition obviously obtaining near the intrusive contacts at a time shortly after the coming to place of the quartz monzonite magma. That tourmaline is an index of formation at high temperature is regarded as established so firmly that argument in support of the fact is unnecessary.

Although it seems clear, therefore, that the ore deposits are closely linked in origin with the intrusion of the quartz monzonite, this causal connection may ultimately be due either to (1) the heat furnished by the magma, thus stimulating the circulation of meteoric waters and increasing their solvent powers, or (2) to the release of metalliferous solutions from the cooling magma, or (3) to combinations of (1) and (2). The current theory of ore deposits holds that the presence of tourmaline, because of its content of boron and fluorine, is proof that the deposits in which it occurs were formed by direct

exhalations from a cooling magma. In the ore deposits here considered, as previously shown, the solutions that carried the elements of the tourmaline carried also those of the metallic sulphides, and the sulphides were formed contemporaneously with the tourmaline. It is therefore probable that the ore-depositing solutions were of magmatic derivation and represent the final manifestation of the intrusive energy of the great quartz monzonite invasion.

The tourmalinization and introduction of the ore took place, however, distinctly later than the intrusion of the aplites, some of which were profoundly altered by the ore-forming solutions. The quartz monzonite magma was therefore not directly the "ore bringer." The release of the metalliferous solutions took place at a more advanced state of magmatic differentiation; in fact, at a stage succeeding the intrusion of the aplite.

The formation of the aplite magma, as pointed out already, was accompanied, as inferred from undoubted facts observed in the field, by an increase in its content of tourmaline to a proportion considerably greater than that in the original quartz monzonite magma. The facts observed in the field suggest a tentative speculation. The concentration of the tourmaline in the aplite magma brought about a further differentiation of which the ultimate product was a highly mobile solution, endowed with great migratory powers. The tourmaline-quartz-orthoclase segregations are regarded as imprisoned and congealed globules of this final differentiate. It is noteworthy that the composition of these tourmalinic segregations is essentially similar to that indicated for the ore-forming solutions by the study of their metasomatic activities. Both contained boron, silicon, aluminum, and potassium. Presumably the increase of tourmaline in the aplite magma was accompanied by a concurrent increase in the concentration of the metallic constituents. But on this point the field evidence fails, for at only one locality was a tourmaline segregation noted to carry a sulphide mineral (pyrite). The phenomena of the ore deposits show that the tourmaline and the metallic sulphides traveled together, but the field evidence does not show how this association was originally brought about.

SYSTEMATIC IMPORTANCE OF TOURMALINIC SILVER-LEAD DEPOSITS.

As is well known, a sharp distinction was drawn by French geologists between the cassiterite-bearing veins and the ordinary sulphide-bearing veins, the so-called "filons plombifères." This division into two classes is recognized by Vogt¹ as valid, only that here, as elsewhere in nature, transitional forms exist. Certain such gradations are pointed out by him, but in conclusion he states that "galena-silver ore veins carrying tourmaline in abundance are not known."

¹ *Genesis of ore deposits: Special publication Am. Inst. Min. Eng., 1902, p. 665.*

A review by Stutzer in 1906 of all known tourmaline-bearing ore deposits confirms this statement. Eight classes are defined, the limits of which are somewhat arbitrary, owing to transitional forms, but tourmalinic silver-lead ore deposits do not appear among them.¹

It is therefore a matter of some theoretic interest to find a series of highly tourmalinic galena-silver lodes genetically related to the intrusion of the Boulder batholith. Tourmaline is the most characteristic mineral of the stanniferous deposits; here in Montana it is developed in extreme abundance as an accompaniment of silver-lead deposits. Moreover, the lodes have been important producers; the largest of these, the Alta, credited with a yield of \$32,000,000, appears, if the stanniferous lodes are excluded, to outrank in value of output any known ore body of the tourmalinic class of deposits.

YOUNGER ORE DEPOSITS (POST-MIOCENE).

GENERAL CHARACTER.

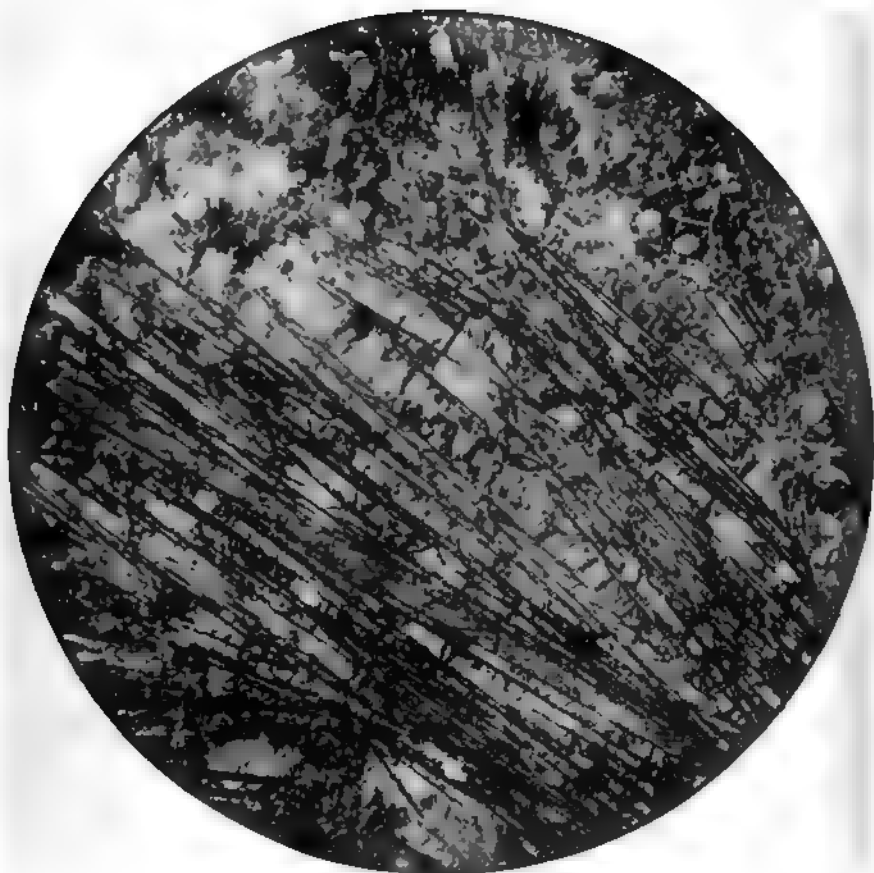
The ore deposits of the postvolcanic mineralization are essentially precious metal deposits. They include gold, gold-silver, and silver deposits.

Unlike the ore bodies of the older group, the younger ore deposits show no significant geologic distribution. They occur generally throughout the region and are inclosed in rocks of all ages—in the dacites and rhyolites, in the quartz monzonite, and in the sedimentary rocks. At certain localities a considerable number of productive veins are massed together, giving rise to mining districts of economic prominence. Districts whose importance has depended on veins of late Tertiary age are Marysville, Clancy, and Lowland Creek. Besides the veins of these districts there are a large number of widely scattered deposits.

The cause of the localization of the deposits in certain districts is not clearly apparent. The most productive portion of the Clancy district, that of Lump Gulch, is situated in the heart of the quartz monzonite area and at a considerable distance from the nearest accumulation of rhyolites; Lowland Creek, which is 14 miles north of Butte, is situated in the middle of the great dacite area extending southward to Butte; the geologic features do not indicate why there should be a grouping of deposits in these localities. On the other hand, the localization of the deposits at Marysville seems plausibly explicable as due in part to the favoring influence of the contact of dissimilar rocks, inasmuch as the deposits are grouped around the margin of a quartz diorite stock in the Belt series.

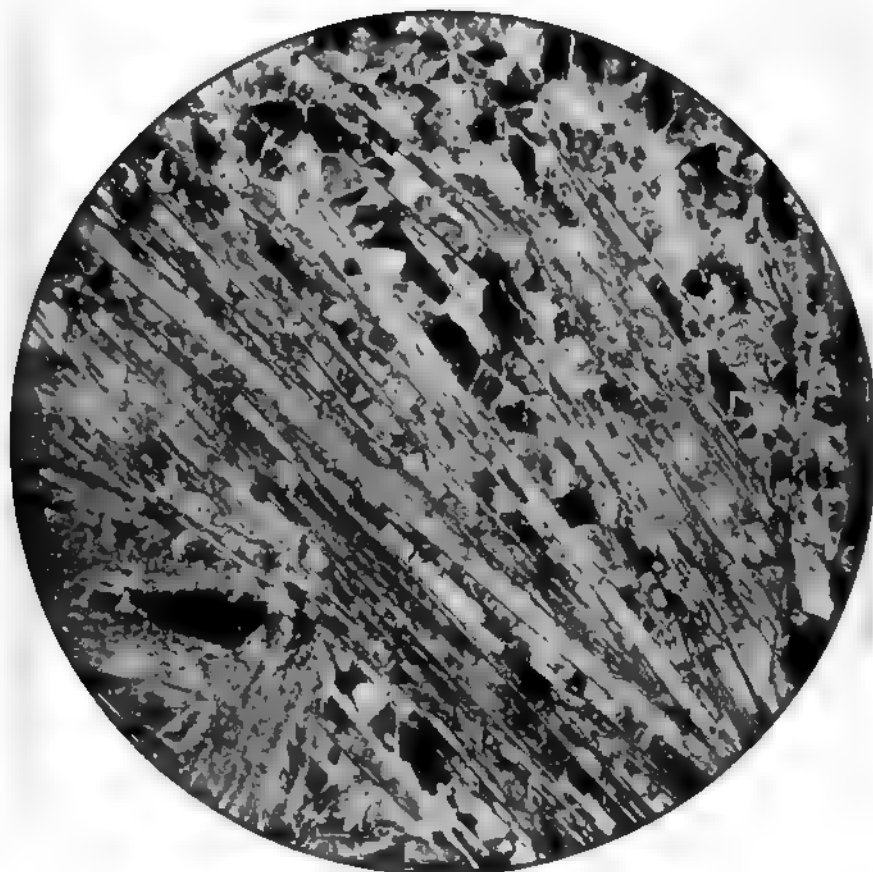
Each of the different districts shows a certain degree of individuality, but the general features in common will be pointed out here; the detailed descriptions must be sought under the various districts.

¹ Stutzer, O., Turmalin führende Kobalterzgänge: Zeitschr. prakt. Geologie, vol. 14, 1906, pp. 294-299.



LAMELLAR CALCITE ORE, BELMONT MINE, MARYSVILLE

Thin section, parallel light, magnified 30 diameters



LAMELLAR CALCITE ORE, BELMONT MINE, MARYSVILLE

Thin section, crossed N. C. S., magnified 30 diameters.

The ore bodies are mainly fissure veins of branching and irregular character. At Rimini, however, there are some extensive deposits of disseminated low-grade gold ore in the rhyolite. As a rule the ore bodies carry subordinate quantities of sulphides and are worked for their content of precious metal alone. A prominent feature of the deposits is the prevalence of cryptocrystalline quartz in the gangue material. The cryptocrystalline quartz appears in three varieties: (1) A dark gray-blue flinty variety, (2) a dense-grained white variety resembling porcelain, and (3) chalcedony. These three modifications, however, are likely to be present together in the same deposit, confusedly intergrown and each variety grading into the other. It is not uncommon to find veinlets lined with chalcedonic quartz which toward the central portion of the veinlets grades into drusy crystalline quartz.

In some deposits, notably in some of those inclosed in the dacites on Lowland Creek, the quartz is pseudomorphic after a thinly lamellar calcite. This has given rise to a gangue of characteristic appearance. The arrangement of the quartz plates is commonly such as to inclose irregular pyramidal spaces, which are lined with innumerable small quartz crystals. The plates are also arranged in radiating groups. On fractured surfaces the partial overlapping of thin superposed plates produces an imbricating structure.

The pseudomorphic lamellar quartz is developed in extraordinary perfection in the veins of Marysville, where in fact considerable quantities of unreplaced lamellar calcite still remain. Plates III and IV are photomicrographs of a thin section of calcite ore from the second level of the Belmont mine, Marysville. The lamellar habit of the calcite and the extreme thinness which the plates attain—some under 0.001 of an inch—are well displayed. Plates V and VI show high-grade ore from the same mine. The ore consists wholly of quartz, much of which shows a lamellar structure in the hand specimen; even in parallel light the replacement structure is brought out by the arrangement of inclusions and is confirmed by the behavior between crossed nicols.

METASOMATIC PROCESSES.

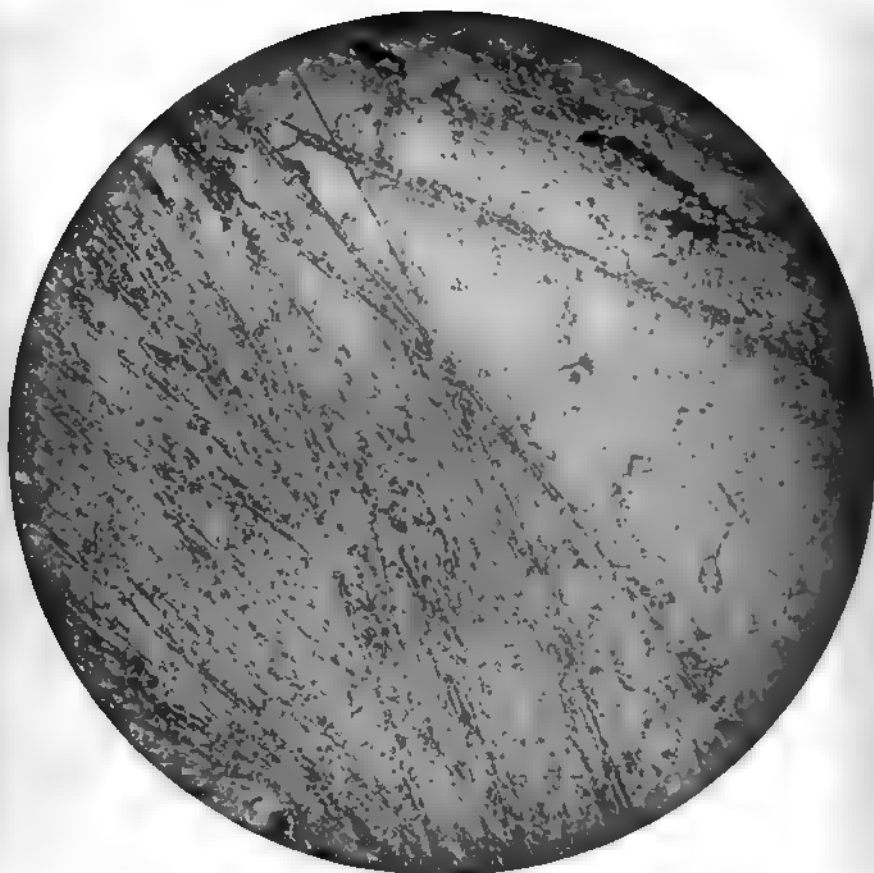
The metasomatic alteration of the wall rocks of the late Tertiary veins is principally in the nature of a thorough sericitization, accompanied by the introduction of carbonates and locally by the development of chlorite. The resulting product is as a rule, widely different in appearance to the eye from the altered wall rocks of the older veins. In the wall rocks of the younger veins the feldspars have, as a rule, been reduced to chalky-white spots suggesting kaolin aggregates, but which prove microscopically to consist of microcrystalline sericite; the wall rock of the older veins are of green glossy appearance, due to the development of sericite flakes sufficiently coarse to be distinctly recognizable by the eye.

In order to determine the chemical processes involved in the alterations produced by the late Tertiary vein-forming solutions, analyses of altered and unaltered rocks adjoining the King Solomon lode were obtained. This lode traverses quartz monzonite and consists of parallel veinlets of galena, sphalerite, and tetrahedrite in a chalcodonic gangue, locally carrying some siderite. The late Tertiary age of the vein is proven by the fact that it is younger than the dacites, a dike of which forms the hanging wall of the lode, as described on pages 104-105. As the quartz monzonite is similar to that at Rimini, the alterations produced during the two contrasted periods of mineralization are directly comparable.

The quartz monzonite is remarkably homogeneous within a radius of several miles of the mine. It is a coarse-grained granitoid of subporphyritic habit, due to the rude development of large sporadic phenocrysts of orthoclase, and consists of plagioclase, orthoclase, quartz, biotite, and hornblende, with a minute amount of finely scattered pyrite. Under the microscope the plagioclase is found to be a zoned andesine near $Ab_{59}An_{41}$, although the periphery is more sodic than this; the orthoclase to be coarse anhedral and somewhat clouded or "watered" from admixed albite; and magnetite, titanite, and apatite to occur as accessories, with a small amount of sericite as secondary mineral.

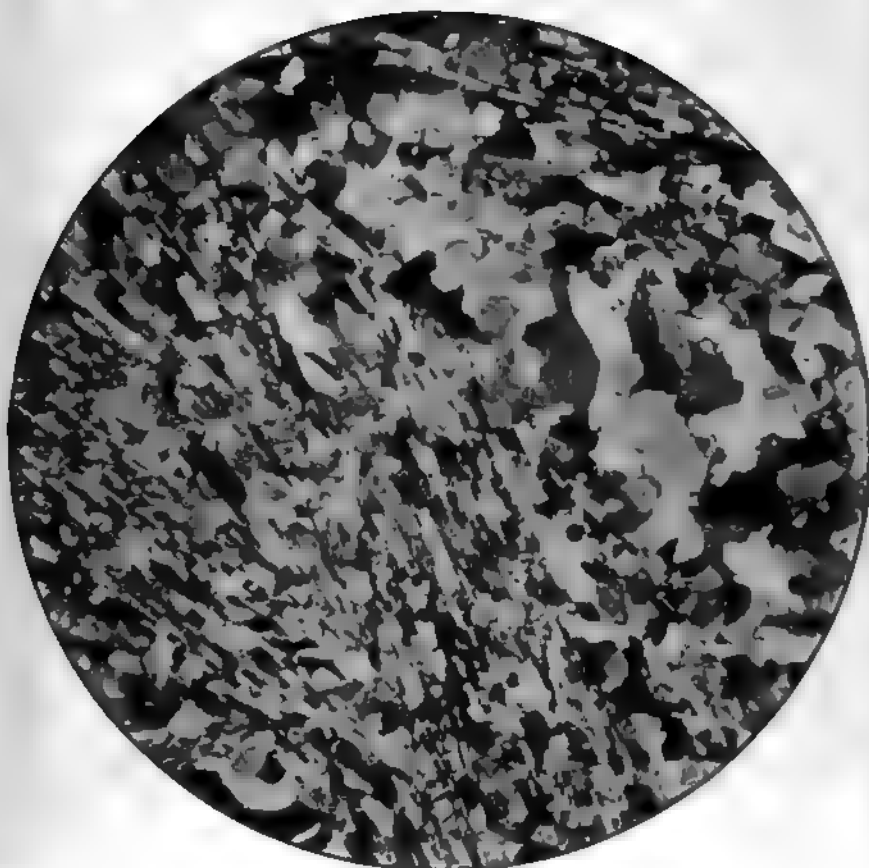
The altered rock, taken from the lode on the 300-foot level, still shows the original texture of the subporphyritic quartz monzonite; quartz is easily recognizable; the plagioclase is represented by dull waxy aggregates of light yellowish-green color; the dark minerals have altered to silvery sericite, and pyrite is present in small amount. In thin section it can be seen that the rock has undergone profound changes. Quartz is the most abundant constituent. Sericite forms exceedingly fine grained dense aggregates, mainly localized in the former plagioclase feldspars, which have disappeared entirely. Microcline appears as large sporadic phenocrysts, representing dynamically altered orthoclase phenocrysts, and microcline and orthoclase as recrystallization products are present in abundance. In the original rock the orthoclase was mainly in the form of large anhedral plates; here it is finer grained and subhedral. Pyrite in small crystals has developed in the biotite and hornblende and is intimately associated with siderite. Another carbonate, which is present as a minor constituent, is probably magnesite, as indicated by the chemical analysis. Apatite and zircon appear as accessories.

The notable mineralogic feature of this wall-rock alteration is the selective sericitization that has taken place; the soda-lime feldspar has been completely transformed to sericite, whereas the orthoclase,



LAMELLAR QUARTZ PSEUDOMORPHIC AFTER CALCITE, BELMONT MINE, MARYSVILLE

Thin section, parallel light, magnified 30 diameters.



LAMELLAR QUARTZ PSEUDOMORPHIC AFTER CALCITE, BELMONT MINE, MARYSVILLE
Thin section, crossed Nicols, magnified 30 diameters.

essentially a potassium feldspar, has remained largely intact, or has been in part recrystallized, although the admixed soda feldspar has been eliminated during the recrystallization.

The mineral composition of the altered and unaltered rocks, computed from the chemical analyses, is as follows:

Mineral composition of fresh and altered quartz monzonite.

	Fresh.	Altered.
Quartz.....	19.86	42.42
Orthoclase (molecule).....	18.90	25.58
Albite (molecule).....	28.80	.....
Anorthite (molecule).....	12.78	.....
Biotite.....	8.94	.....
Hornblende.....	7.26	.....
Magnetite.....	.70	.....
Titanite.....	.59	.....
Apatite.....	.31	.31
Pyrite.....	.13	.45
Calcite.....	1.00	.....
Siderite.....	.....	2.44
Magnesite.....	.....	.67
Sericite.....	.....	26.86
Water (excess).....	.38	.29
	99.65	99.02

The specific gravity of the fresh quartz monzonite as determined on a rock specimen is 2.714; calculated from the computed mineral composition it is approximately 2.712. The porosity is therefore probably very small.

The specific gravity of the altered rock as determined on a rock specimen is 2.599; calculated from the computed mineral composition it is approximately 2.695. The computed porosity is accordingly 3.6 per cent. The alteration of the wall rock by the vein-forming solution has therefore been accompanied by a small increase of porosity.

In the preceding computation the conventional formula of sericite, $K_2O.2H_2O.3Al_2O_3.6SiO_2$, has been used. The result conflicts apparently with the microscopic diagnosis, which indicates a considerably larger quantity of sericite than 26.86 per cent. Probably the use of the formula of a less aluminous mineral, corresponding to Sandberger's lepidomorphite, $K_2O.2H_2O.2Al_2O_3.7\frac{1}{2}SiO_2$, or of an admixture of this mineral would yield a more harmonious result.

The chemical analyses and computations to show the percentage gain or loss of the different constituents during metasomatic alteration follow. These computations are based on the assumption that the volume changes are zero; that this assumption is fully justified is proved by the fact that the altered wall rock still retains the subporphyritic habit and granitic structure of the fresh quartz monzonite.

Comparison of fresh and altered quartz monzonite from the King Solomon mine, Clancy, Mont.

	1	2	1a	2a	3	4	5
SiO ₂	64.49	71.22	175.00	185.00	+10.0	+ 6.68	+3.69
Al ₂ O ₃	15.49	15.05	42.00	39.10	- 2.9	- 6.90	-1.07
Fe ₂ O ₃	1.28	Trace.	3.47	.....	- 3.47	-100.0	-1.28
FeO.....	2.71	1.54	7.35	4.00	- 3.35	- 45.5	-1.23
MgO.....	1.89	.33	5.13	.86	- 4.27	- 83.3	-1.57
CaO.....	4.32	Trace.	11.72	.....	-11.72	-100.0	-4.32
Na ₂ O.....	3.53	.42	9.58	1.09	- 8.49	- 88.6	-3.13
K ₂ O.....	4.04	6.99	10.96	18.16	+ 7.20	+ 65.7	+2.65
H ₂ O-.....	.16	-.32	.....	.....	.....	.....	.....
H ₂ O+.....	.48	1.52	1.30	3.95	+ 2.65	+203.8	+ .98
TiO ₂.....	.56	.31	1.52	.81	- .71	- 46.7	-.26
CO ₂.....	.49	1.50	1.33	3.90	+ 2.57	+193.2	+ .95
P ₂ O ₅.....	.19	.08	.52	.28	.....	.....	.....
MnO.....	.07	.05	.19	.13	.....	.....	.....
BaO.....	.06	None.	.16	.....	.....	.....	.....
FeS ₂.....	.13	.45	.35	1.17	+ .82	.....	+ .30
	99.80	99.78	270.58	258.45	.....	.....	-4.23
Specific gravity.....	2.714	2.599	.....	.....	.....	.....	.....

- 1. Chemical composition of fresh quartz monzonite. J. G. Fairchild, analyst.
- 2. Chemical composition of altered quartz monzonite. J. G. Fairchild, analyst.
- 1a. Constituents in 100 cubic centimeters of fresh rock.
- 2a. Constituents in 100 cubic centimeters of altered rock.
- 3. Gain or loss in grams of each constituent during alteration.
- 4. Gain or loss in percentage of original mass of each constituent.
- 5. Gain or loss in percentage of original mass of the fresh rock.

The computations show that there has been a net loss of material amounting to 4.23 per cent. There have been heavy gains in silica and potash and additions of water and carbon dioxide, but these gains are unable to offset the heavy losses in alumina; ferric and ferrous iron, magnesia, lime, and soda.

AGE AND ORIGIN OF THE YOUNGER ORE DEPOSITS.

The ore deposits of this group are post-Miocene in age. This determination is based on the fact that veins of this group are inclosed in dacites on Lowland Creek which are known to be of upper Miocene age. It is a fairly safe presumption that they were formed relatively near the surface, although it is to be noted that if they were formed immediately after the cessation of volcanic activity they may possibly have originated at a depth of 2,400 feet.

The cryptocrystalline and chalcedonic character of the quartz gangue, the content of adularia, and the lamellar calcite and pseudomorphic quartz ally these veins on Lowland Creek with those common in the late Tertiary lavas in the western mining States. Many, such as those at De Lamar, Idaho,¹ and Jarbidge, Nev.,² are identical in mineralogy and structure. Furthermore it is perhaps significant that the calcite in the veins from which hot water is trickling at Boulder Hot Springs has a lamellar structure; the silica in the gangue is cryptocrystalline, chalcedonic, and opaline.

¹ Lindgren, Waldemar, Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, p. 106.
² Schrader, F. C., A reconnaissance of the Jarbidge, Contact, and Elk Mountain mining districts, Elko County, Nev.: Bull. U. S. Geol. Survey No. 497, 1912, pp. 52-58.

Partly because of the striking analogy between the Marysville veins and those of Lowland Creek and other late Tertiary veins throughout the Western States and partly because of other reasons, as detailed under the head of Marysville district, the deposits at Marysville are regarded as of post-Miocene origin, although the evidence from a purely local study of the geology at Marysville strongly favors the idea that the deposits are genetically related to the intrusion of an outlier of the Boulder batholith. It is believed in this connection that one of the more important results of the present investigation is that it shows clearly the necessity of a broad regional study in approaching the problems of ore genesis at any one locality.

The true silver veins of the Clancy and Lump Gulch districts differ somewhat from the preceding deposits, but their late Tertiary age is proved by the fact that they were formed after the intrusion of dacitic dikes. The chalcedonic character of the gangue material is in harmony with their post-Miocene age; in fact this feature is alone sufficient to differentiate them from the older (late Cretaceous) deposits. The study of the wall-rock alterations produced by the ore-forming solutions of this group of deposits shows that the solutions were particularly rich in potassium and silica, and carried carbon dioxide, sulphur, antimony, lead, zinc, copper, and silver. They were strongly reducing and were deficient in iron, calcium, sodium, magnesium, and aluminum. The chemical work which they accomplished shows that they were ascending thermal solutions.

As to the source of these solutions the evidence is as obscure as it is correspondingly clear for the older or batholithic deposits. These deposits were formed from metalliferous solutions expelled from the final differentiate of the quartz monzonite magma. But that the post-Miocene veins are related to the intrusion or extrusion of any igneous rocks is not clear. That they followed the extravasation of the dacites is obvious, but how close this sequence was can not be determined. The distribution of the veins shows no significant relation to the dacites; if the veins are genetically related to the dacites it might confidently be expected that an unusual number of veins would be grouped around old volcanic vents, where communication was most ready with the underlying sources of supply. So far as the geology of the region is now known the Big Butte at Butte is the only recognized vent from which dacites were erupted. Nevertheless the ore deposits at Butte were all formed prior to the eruption of the dacitic lavas, which are said to cover and conceal them.¹

¹ Weed, W. H., *Geology and ore deposits of the Butte district, Montana*: Prof. Paper U. S. Geol. Survey No. 74, 1912, p. 43.

COMPARISON OF THE METASOMATIC PROCESSES OF THE TWO PERIODS OF MINERALIZATION.

The ore deposits of the first period of mineralization are clearly of high-temperature origin and belong to the so-called deep-zone group of deposits; those of the second period—the post-Miocene deposits—belong to the shallow-zone group. As the older deposits at Rimini and the younger deposits at Clancy are inclosed in quartz monzonite of nearly similar composition direct comparisons can be instituted between the metasomatic processes operative during the two periods of mineralization.

In the wall-rock alteration of the first period the quartz monzonite has been transformed completely to a quartz-sericite rock carrying abundant metallic sulphides; in extreme phases of alteration the transformed rock is analogous to a fine-grained greisen carrying accessory tourmaline. In the wall-rock alteration of the second period the sericitization has been selective; the plagioclase has been completely altered to sericite, but the orthoclase has been unaffected by this change. In further contrast to the earlier mineralization the introduction of metallic sulphides into the wall rock has been insignificant, but water and carbonates have been introduced in noteworthy amounts.

In order to facilitate the comparison, certain of the analyses and computations are assembled in the table below.

Comparison of fresh and altered quartz monzonite from Rimini and Clancy.

	1	2	1a	2a	1b	2b
SiO ₂	65.91	64.49	66.02	71.22	+6.12	+3.69
Al ₂ O ₃	15.32	15.49	14.14	15.05	+ .10	—1.07
Fe ₂ O ₃	2.28	1.28	1.53	Trace.	— .61	—1.28
FeO.....	2.02	2.71	.37	1.54	—1.62	—1.23
MgO.....	1.52	1.89	.67	.33	— .79	—1.57
CaO.....	3.28	4.32	.26	Trace.	—3.00	—4.32
Na ₂ O.....	3.08	3.53	.39	.42	—2.65	—3.13
K ₂ O.....	4.80	4.03	4.63	6.99	+ .20	+2.65
H ₂ O+.....	.60	.16	.10	.32	.....	.....
H ₂ O -.....	.60	.48	.48	1.52	.....	+ .98
TiO ₂.....	.59	.56	.56	.31	.....	— .26
CO ₂.....	.21	.49	.25	1.50	.....	+ .95
P ₂ O ₅.....	.18	.19	.17	.08	.....	.....
BaO.....	.10	.06	.04	None.	.....	.....
MnO.....	.....	.07	.....	.06	.....	.....
PbS.....	.....	.....	2.02	.....	+2.20	.....
ZnS.....	.....	.....	.74	.....	+ .81	.....
FeAsS.....	.....	.....	.72	.....	+ .78	.....
FeS ₂.....	.....	.13	6.73	.45	+7.33	+ .30
	100.51	99.80	99.82	99.78	+8.87	—4.23

1. Fresh quartz monzonite, Rimini.
2. Fresh quartz monzonite, Clancy.
1a. Altered quartz monzonite, Rimini.
2a. Altered quartz monzonite, Clancy.
1b. Gain or loss in percentage of original mass of the unaltered rock, Rimini.
2b. Gain or loss in percentage of original mass of the unaltered rock, Clancy.

The difference between the alterations produced during the contrasted periods of mineralization is readily apparent, but its inter-

pretation is an open question, for part of the difference may be due to difference of temperature and part due to difference in the composition of the solutions.

The most striking contrast is that a net increase in mass of 9 per cent has been produced by the earlier mineralization and a net loss of 4 per cent has taken place during the post-Miocene mineralization. So far as the metasomatic record indicates the early or high-temperature alteration might have been produced by anhydrous solutions, for the altered wall rock shows an actual decrease of water content, whereas the late Tertiary, a low-temperature alteration, shows a noteworthy increase. Moreover, during the high-temperature alteration no carbonates were formed, but only during the low-temperature mineralization.

DESCRIPTIONS OF SPECIAL DISTRICTS.

METHOD OF TREATMENT.

In the preceding pages the region has been treated as a unit. The different mining districts, however, differ somewhat among themselves in their geology and in the character of their ore deposits, so that for the sake of definiteness and explicitness descriptions of the special districts are added. These descriptions are generally brief and the broader relations of the geology at any locality and the detailed characterization of the formations must be sought under the preceding systematic treatment.

The districts employed here conform to no political subdivisions. They include the areas easily reached from the natural supply points of the region and their boundaries are accordingly somewhat indefinite. In this respect the scheme accords essentially with local usage.

MARYSVILLE DISTRICT.

LOCATION AND HISTORY.

Marysville is situated in Lewis and Clark County at an elevation of 5,600 feet, 17 miles northwest of Helena. It is the terminal point of a branch from the main line of the Northern Pacific Railway. A number of mining camps now idle, including Bald Butte, Empire, and Gloster, are tributary to Marysville.

The prosperity of Marysville has hinged largely on the fortunes of the Drumlummon mine, the oldest, most steadily operated, and most productive property of the district. The Drumlummon lode was discovered in 1876 by Thomas Cruse, who had been placer mining in Silver Creek, below the present site of Marysville, and the mine was gradually developed by him until 1880, when a 5-stamp mill was erected. In 1882 the property was sold to an English company, known as the Montana Mining Co. (Ltd.), for \$1,500,000. During the

operations of this property \$15,000,000 was extracted. In the early nineties the property became involved in protracted litigation, which extended over some 18 years, and the mine in recent years has been worked only spasmodically. Finally the property was sold in default of payment to satisfy a judgment of \$240,000 rendered against the Montana Mining Co. (Ltd.), and was bought in 1911 by the successful litigant, the St. Louis Mining & Milling Co. The new owner has commenced to rehabilitate the milling plant, to open the old workings, which had caved badly, and to search for new bodies of ore.

Other notable mines in the district are the Belmont, Cruse, Penobscot, Bald Butte, Empire, and Piegan-Gloster, but all of these were idle during 1911 except the Cruse or Bald Mountain mine.

The total production of the district has been approximately \$30,000,000 in gold and silver.¹ In 1910 the production was \$145,663 and in 1911 it was \$165,832, distributed as follows: Gold, \$143,918, and silver, \$21,914.

GEOLOGY.²

Geologically, the Marysville district is situated on and around a small stock of quartz diorite intrusive into limestones and shales of the Belt series. This intrusive mass represents without question an outlier of the Boulder batholith, the main body of which appears at Mullan Pass, 7 miles south of Marysville.

The sedimentary rocks surrounding the quartz diorite have been thoroughly metamorphosed to exceedingly hard, tough, and dense-textured rocks termed hornstones by Barrell. These are made up mainly of various silicates, such as diopside, wollastonite, tremolite, and biotite, but these minerals as a rule are not visible or discriminable by the eye. In local parlance the rocks are somewhat vaguely known as slates. They form a zone around the quartz diorite, ranging in width from one-half mile to two miles, and grade outward from the diorite stock into the unaltered siliceous shales and limestones of the Belt series.

The quartz diorite is a medium-grained granitic rock composed essentially of andesine, quartz, orthoclase, biotite, and hornblende. Younger than the quartz diorite are a variety of dikes, some of which seem from their petrographic characters to belong to the intrusive aftereffects of the quartz diorite magma. These minor intrusions comprise aplite, pegmatite, and the Belmont diorite porphyry, so named because of its noteworthy abundance on the slopes of Mount Belmont. The aplites are not important quantitatively and the pegmatites are nearly insignificant, but the diorite porphyry occurs in considerable abundance as persistent dikes.

¹ Weed, W. H., Gold mines of the Marysville district, Mont.: Bull. U. S. Geol. Survey No. 213, 1903, p. 88.

² The geology of the district has been carefully described in great detail by Joseph Barrell in *Geology of the Marysville mining district, Mont.*: Prof. Paper U. S. Geol. Survey No. 57, 1907.

Among the more prominent of these is the long dike at the Bald Butte mine. The diorite porphyries are rocks of conspicuously porphyritic texture, containing prominent crystals of andesine feldspar, together with prisms of hornblende and flakes of biotite in lesser amounts, in a dark-gray groundmass. The feldspar phenocrysts are more numerous and the groundmass more crystalline in those dikes near the main mass of quartz diorite; in fact, in some of them the feldspar phenocrysts are so thickly massed and the matrix so visibly crystalline that the rock closely resembles the quartz diorite. This assumption of granitoid habit by the dikes within the inner metamorphic zone is believed by the writer to be significant and to indicate that the diorite porphyry dikes were injected soon after the main intrusion of the quartz diorite.

Other dikes whose genetic relations are less obvious are the Drumlummon porphyry and the porphyry sheets of Piegan Gulch. That there is a possibility that these various intrusives, including the diorite porphyries, do not all belong to the same stage of igneous activity was recognized by Barrell,¹ but not much importance was attached to it. The determination of the age of these dikes, however, would afford an independent line of evidence on the question concerning the origin of the Marysville ore deposits.

The Drumlummon porphyry is principally encountered in the workings of the Drumlummon mine, which lies at the contact of the quartz diorite and hornstones. The rock is a grayish porphyry carrying small scattered phenocrysts of plagioclase feldspar inclosed in an aphanitic groundmass. These prove under the microscope to be near andesine in composition; the dark minerals once present are found to have been destroyed by vein-forming solutions, and the groundmass is seen to consist of feldspar and quartz.

The porphyry of Piegan Gulch, so far as is now known, occurs in the Marysville area in three sills, a mile north of Gloster, but is found in great abundance in other parts of the region, as shown in previous pages of this report, where it is termed dacite. The porphyry of Piegan Gulch shows phenocrysts of chalky feldspar, biotite, and quartz in a dense gray groundmass. Under the microscope the feldspars are found to be a plagioclase near andesine, which has been largely altered to calcite. Possibly some sanidine is present. The quartz crystals, which are comparatively rare, show strong magmatic corrosion; the biotite phenocrysts are largely calcitized and sericitized; the groundmass in which the phenocrysts rest is of cryptocrystalline texture. The rock accordingly resembles the dacites from surrounding parts of the general region.

The nearest important development of dacites is east of Silver City, 7 miles east of Marysville; rhyolites, which are closely related

¹ Op. cit., p. 49.

to the dacites, occur south and southwest of Marysville, an especially large area extending north from Mullan Pass, and dacites or rhyolites are associated with the extrusive andesites of Little Prickly Pear Creek, a few miles north of Marysville. It is therefore not surprising that isolated dikes of this character should occur within the district, although, as pointed out elsewhere, it is difficult to distinguish isolated dacite dikes from quartz diorite porphyry dikes, and the study of the local geology would afford no clue to their origin.

The dacites found at Marysville show the hydrothermal alteration characteristically associated with the late Tertiary veins, and this fact suggests, although it does not prove, that the principal mineralization took place in late Tertiary time.

ORE DEPOSITS.

GENERAL FEATURES.

The ore deposits are steeply dipping fissure veins carrying gold and silver. They occur around the border of the quartz diorite, and although some are situated in the marginal portion of the diorite, most of the veins are inclosed in the metamorphic hornstones. None occur in the central part of the diorite area. This massing of a considerable number of productive ore bodies around the diorite is the cause of the economic importance of the Marysville district.

The veins average near 1,000 feet in length; the Drumlummon, which is the longest, was developed for a distance of 3,000 feet along the strike. The maximum width of the ore bodies is 40 feet, but the average is considerably less than this, in most of the veins being probably less than 6 feet. The ore occurred in shoots in which the high-grade ore was found above the 200-foot level; none of the mines, except the Drumlummon, are developed deeper than 500 feet below the surface. Gold is the predominantly valuable metal and the ores range between \$10 and \$20 a ton.

The gold is finely divided and not visible. In the ore of many mines—the Belmont, Empire, and others—it is unaccompanied by sulphides or by insignificant quantities only. In the Drumlummon it is accompanied mainly by tetrahedrite and chalcopyrite, and in the Bald Butte mine by pyrite, sphalerite, and galena. The gangue material is of highly characteristic composition and structure. It consists of quartz, commonly of lamellar habit, and calcite in broad, thin lamellæ. At the Bald Butte mine fluorite occurs, but this is exceptional, for fluorite has not been noted at any other mine in the district. In many of the typical ores of Marysville the calcite lamellæ attain great breadth and extraordinary thinness, at the Empire mine, for example, the extreme diameter being 6 inches and the thickness only one-fiftieth of an inch. The calcite plates are commonly

arranged so as to form rude tetrahedral or other irregular pyramidal forms. The quartz is a sugar-textured white variety, commonly pseudomorphic after lamellar calcite. This gives rise to hollow tetrahedral spaces, which are lined with small clear glassy pyramids of quartz. In places the quartz is pseudomorphic after thin curved lamellæ of calcite, and a foliated or schistose structure results. Rarely the quartz shows a delicate amethystine tint.

The calcite carries some iron and manganese and in consequence the outcrops of some of the veins are highly manganiferous. Probably this prevalence of manganese is in part responsible for the enrichment in gold of the upper zone of the Marysville veins. Impoverishment of the outcrop, however, as demanded by Emmons's theory,¹ has not taken place.

The lamellar quartz and calcite form a striking gangue material. It is identical with the gangue of the gold-silver veins in the Miocene dacites on Lowland Creek and resembles the calcite gangue in the veins from which hot water is oozing at Boulder Hot Springs. Further, it resembles the lamellar quartz ore of the De Lamar mine, Idaho, described by Lindgren in his paper on the gold and silver veins in Idaho, and well illustrated in Plate XXVIII of that report.² Similar ore occurs also in many of the late Tertiary veins in Nevada, Utah, Arizona, New Mexico, and Washington.

ORIGIN.

The study of the ore deposits in the area of the Boulder batholith has shown that they fall into two groups, whose age with reference to the rhyolites and dacites resting on the eroded surface of the granite has been determined absolutely. The older group is of prevolcanic origin and is genetically related to the intrusion of the granite; the younger group is of postvolcanic origin. Each group carries a distinctive set of features generally sufficient for the determination of the relative age of a particular ore deposit even where the relation of the ore deposit is not absolutely determinable owing to the absence of the volcanic rocks.

So far as the geology of the Marysville district is now known, the age of the productive ore deposits can not be conclusively established with reference to the Tertiary volcanic rocks. Possibly the productive deposits may prove to be the equivalents of the barren veins north of Little Prickly Pear Creek, which are known from undisputable geologic evidence to be of late Tertiary age,³ but the matter has not been investigated adequately with this point in view. On the

¹ Emmons, W. H., The agency of manganese in the superficial alteration and secondary enrichment of gold deposits in the United States: Trans. Am. Inst. Min. Eng., vol. 41, 1910.

² Lindgren, Waldemar, Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900.

³ Barrell, Joseph, Geology of the Marysville mining district, Mont.: Prof. Paper U. S. Geol. Survey No. 57, 1907, pp. 112-113.

other hand, the criteria for the recognition and discrimination of the younger deposits from the older group point unmistakably to the conclusion that the Marysville veins belong to the younger or late Tertiary deposits. This conclusion, following inevitably from a regional study of the ore deposits of the Boulder batholith, is opposed to the conclusion arrived at by Barrell from an intensive study of the local geology.

According to Barrell¹ the Marysville veins—

as shown by their structural and mineralogical features, are due to contraction effects on the margins of the granite mass, at that time recently solidified and cooling.

The structural evidence consists of the relation of the veins to the vicinity of the contact, or at least to the metamorphic zone; the fact that their courses are either approximately parallel or at high angles to this contact surface; the parallel and branching character of the fissures; the generally shattered and infiltrated character of the walls; the dying out of the vein fissures, many of which are continued in parallel lines offset to one side; and, lastly, the absence of marked throw along the fissure planes.

The mineralogical evidence is found most clearly in the study of the vein fillings and alteration of the walls in the Bald Butte mine, since it is believed that fluorite, which is there a characteristic mineral, is indicative of magmatic emanations, though the deposition may take place under hydrothermal as well as under pneumatolytic conditions. Fluorite is often found in the contact aureole of granitic masses and is presumably given off as acidic vapors in water solutions from solidifying magmas. The probability of this view of the origin of the vein fissures is seen when the effects of such contraction from cooling are considered in some detail. The central portions of a granite intrusion the size of the Marysville batholith would cool slowly and as a whole; the contraction would be equal throughout; and there would be little or no tendency to form wide contraction cracks in any direction. This agrees with the absence of vein fissures in the center of the intrusion. The cooling of the zone of contact metamorphism and of the marginal portions of the batholith, however, would result in a shrinkage away of those portions from the surrounding rocks, producing fissures parallel to the contact; while the lessened circumference of the outer zone, caused by its cooling before the center, would tend to set up another set of fractures more or less radial in nature.

That the veins are massed around the intrusive contact of the quartz diorite is a strong argument in favor of their genetic dependence on the intrusion of the igneous rock. But the argument of itself is not conclusive. The opening of the fissures may have been long posterior to the consolidation of the diorite; it is well known that the contacts of dissimilar rocks are favorable loci for dynamic action and therefore the deposits may have been localized in the brittle hornstones because of their superior frangibility. "The parallel and branching character of the fissures; the generally shattered and infiltrated character of the walls; the dying out of the vein fissures, many of which are continued in parallel lines offset to one side; and, lastly, the absence of marked throw along the fissures planes," can hardly be accepted as proof of the contractional origin of the Marysville fissures. These structural features are of common occurrence in late Tertiary veins which cut surface lava flows and are therefore as indicative of frac-

¹Op. cit., p. 105.

turing under light load as they are of contraction during the cooling of plutonic rocks. In the region considered in this report all these structural features are found in the post-Miocene veins on Lowland Creek, as is well exemplified in the Ruby mine, described on pages 125-127.

Says S. F. Emmons:¹

Some writers on ore deposits speak of vein fissures as sometimes resulting from contraction, but I have yet to learn of a well-authenticated instance. I regard a certain amount of movement as necessary to break the cohesion between the respective walls of a joint or fissure sufficiently to make a water channel. This I hold to be true also of eruptive contacts. * * * It is to be noted that a contraction fissure could not extend from one rock into another.

Yet the continuity of the Marysville veins across intrusive contacts, as exemplified in the Belmont, Cruse, and Drumlummon mines, is a salient characteristic of many of the ore bodies. Further, numerous mechanical features, such as brecciation and faulting—all prior to the filling of the veins—indicate considerable movement, even if only of oscillatory character, during the opening of the fissures. These facts would seem to place the burden of proof on one who maintains the contractional origin of the Marysville fissures.

The mineralogic evidence adduced by Barrell seems unfortunately chosen. The Bald Butte mine, the only mine in which fluorite is found, is not characteristic of the mines that have yielded 95 per cent of the production of the Marysville district. Nor is fluorite necessarily indicative of magmatic emanations, and its presence assuredly does not prove that veins containing it are genetically related to plutonic igneous rocks. It occurs in the late Tertiary veins of New Mexico and is even now being deposited by the hot springs at Ojo Caliente.² According to Lindgren, fluorite is a persistent mineral and is of little value in determining the genesis of a deposit. Its presence is therefore not incompatible with the late Tertiary origin of the veins at Marysville; nevertheless it can be conceded that the Bald Butte ore is of magmatic derivation without affecting the argument in regard to the origin of the majority of veins of the district.

The characteristic veins of Marysville, comprising those that yielded 95 per cent of the production, have a gangue identical in structure and composition with that of the veins in the dacites of Lowland Creek; that is with the veins of proved post-Miocene age. This striking gangue, the lamellar calcite and pseudomorphic lamellar quartz, is of wide occurrence in the late Tertiary deposits of the Western States, and this circumstance indicates that peculiar conditions were responsible for this type of ore. The widespread condition common to all the deposits was probably deposition near the surface. For De Lamar, Idaho, Lindgren has estimated that the deepest ore bodies

¹ Suggestions for field observations of ore deposits: Min. and Sci. Press, vol. 95, 1907, p. 18.

² Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: Prof. Paper U. S. Geol. Survey No. 68, 1910, pp. 70-73.

were formed at a depth of 700 feet.¹ Further confirmatory evidence is the fact that the Marysville quartz is in general exceedingly dense or porcelainoid in texture, agreeing thus with the younger veins rather than the older, which are characterized by coarse-grained quartz. Then, too, the metasomatically altered wall rocks, when directly comparable, resemble those accompanying the younger deposits. Tourmaline, which is so conspicuously developed in most of the older deposits of the Boulder batholith, is entirely absent; so also, is that coarse sericitization which yields a macroscopic sericite of glossy habit. On the other hand, the feldspars have been reduced to chalky spots of cryptocrystalline sericite, and chloritization and calcitization, both of which are absent from the older deposits, are common alterations. In short, the Marysville deposits are in no way like those of the older group; on the other hand, they closely resemble those of the younger group.

It may, perhaps, be argued that the Marysville veins are nevertheless genetically related to the intrusion of the quartz diorite, but represent a later phase of the same mineralization to which the older group of deposits belongs. A strong objection to this argument from a theoretical standpoint is the fact that the Marysville veins were first filled with lamellar calcite and that this was subsequently replaced by quartz. This sequence of mineralization is in direct contravention of the sequence of magmatic emanations, according to which the carbonate stage should come last and not first.² The veins show internal evidence of two phases of mineralization, both similar to those shown by the late Tertiary veins, but neither is analogous to any phase of mineralization of the older deposits, and this objection, based upon field evidence, seems conclusive against the argument that the Marysville veins represent a final stage of the older mineralization.

DESCRIPTIONS OF MINES.

DRUMLUMMON MINE.

The Drumlummon mine is worked principally through the Maskelyne tunnel, a 1,200-foot crosscut intersecting the lode at a depth of 400 feet. At the intersection a shaft was sunk to the 1,600-foot level, but it is now filled with water. The vein has been developed along the strike for a distance of 3,000 feet, but because of caved stopes most of this part of the vein was inaccessible during 1911.

Much of the material filling the caved stopes is said to constitute low-grade milling ore, and it is now being drawn off and sent to the mill. Twenty stamps of the old 60-stamp mill have been put in working condition by the new owner, the St. Louis Mining & Milling Co., and

¹ Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, p. 165.

² Clarke, F. W., The data of geochemistry, 2d ed.: Bull. U. S. Geol. Survey No. 491, 1911, p. 275.

the crushing of ore was commenced again in July, 1911. In addition to the ore taken out through the Maskelyne tunnel, surface ore was being mined through the Roadside tunnel on the Nine-Hour claim, which is situated on the southwest end of the Drumlummon vein. This ore is stated to carry from \$35 to \$80 a ton and constitutes, therefore, shipping ore, which is sent to the smelter at East Helena.

The total production of the mine has been \$15,000,000, of which 60 per cent was in gold. The surface ores were of high grade, probably comparable to that now taken from the Nine-Hour claim, but the ore mined during the later years of the operations of the Montana Mining Co. was of medium grade only, containing one-half ounce of gold and from 7 to 12 ounces of silver a ton.¹

The Drumlummon vein parallels the contact of the granite and hornstones, having a general trend of N. 15° E. and steep easterly dip. Extensive pits due to caving mark the course of the vein on the surface and show clearly that the wall rocks consist mainly of dense-grained banded hornstones, which are cut irregularly by granitic dikes and by small aplite dikes. The aplite dikes are shattered and in places are mixed with the general country rock. The hornstones are the metamorphic equivalents of the banded phase of the Helena limestone of Algonkian age, and when examined microscopically are found to consist essentially of diopside and wollastonite, which explains why these so-called slates prove so extraordinarily difficult to drill. Porphyry dikes are also encountered in the mine, as discussed by Barrell.²

As seen on the 400-foot level, the Drumlummon vein has a well-defined footwall, strongly wavy and heavily corrugated. The corrugations trend vertically, and the striæ and surface protuberances show that the hanging wall moved downward on the footwall. In places a layer of attrition product 1 to 1½ feet thick rests on the footwall; in places there are a number of superposed false walls above what may be termed the real or ultimate footwall. The hanging wall of the vein consists of a well-defined plane, but the country rock, as shown by a short crosscut south of the shaft, is more or less interlaced with quartz-calcite veinlets to a distance of at least 10 feet. In places the fissure continues, but the filling of the vein consists of barren detritus from the wall rocks. In the south end of the vein, according to J. E. Clayton,³ "the quartz gangue gives out entirely and the filling between the walls is nothing but crushed shale and abraded material from the walls of the fissure." This feature is particularly well shown on the Nine-Hour claim, where numerous open cuts have been made during the progress of litigation to show the

¹ Bayliss, R. T., *Trans. Am. Inst. Min. Eng.*, vol. 26, 1897, p. 33.

² *Geology of the Marysville mining district, Mont.*: Prof. Paper U. S. Geol. Survey No. 57, 1907, p. 108.

³ *Eng. and Min. Jour.*, vol. 46, 1888, p. 106.

continuity of the vein. The fissure, which is some 25 feet wide, is barren here—that is, devoid of quartz—and the filling consists of broken country rock, more or less stained with iron oxide. The foot-wall is marked by a strongly slickensided plane. All these features indicate that powerful forces were operative during the formation of

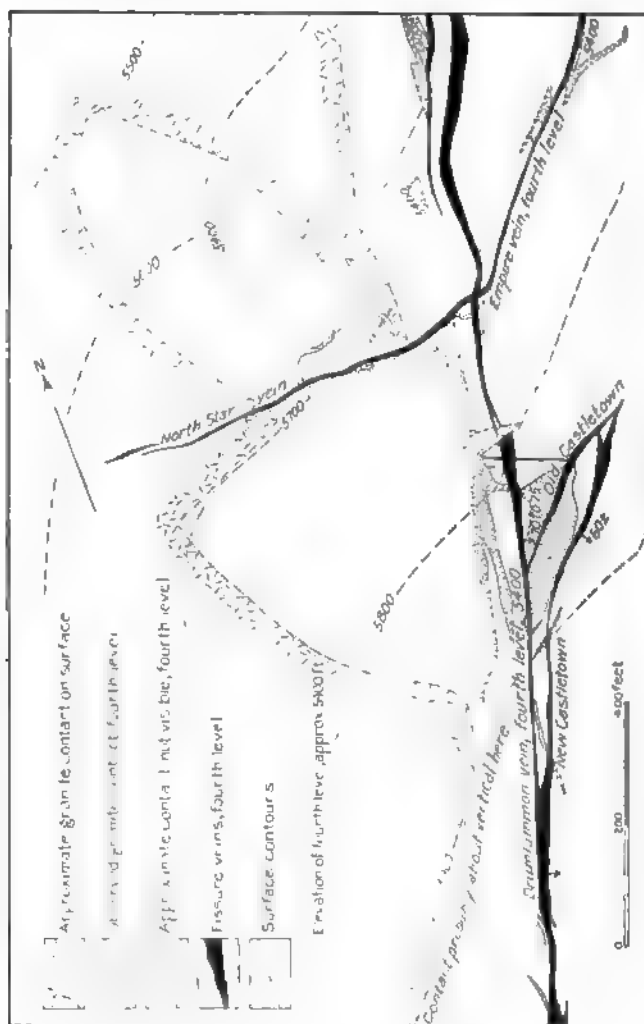


FIGURE 4.—Drumlunnon vein system on the level of the Maskelyne adit (from Barrell).

the Drumlunnon fissure and prove beyond question that its opening was not due to contraction produced by the cooling of the surrounding rocks after the intrusion of the granite.

The New Castletown and Old Castletown veins are branches of the Drumlunnon vein, as shown in figure 1. The North Star is an intersecting vein. According to Clayton it is older than the Drumlunnon; according to Barrell it is younger.

The ore occurred in pay shoots, which in places expanded to a maximum width of 40 feet, but on the whole averaged 20 feet in width. The shoots pitched obliquely to the south within the plane of the vein, the direction being determined by the structural features of the vein. The wavy character of the walls causes the vein to swell and pinch along the strike and on the dip, and the expanded portions of the vein are found farther south on successively lower levels. The cause of this southward pitch of the ore shoots is clearly explained by Clayton:¹

The shifting of the hanging wall has been nearly straight down the slope of the underlie, and the curvatures, or wave lines of the fissure, pitch down obliquely to the south, corresponding generally with the pitch of the ore shoots in that direction.

The rich ore of the mine occurred mainly above the 200-foot level, and an impoverishment of the ore shoots began to be noticed below the 400-foot level. Good ore, however, was found down to the 1,000-foot level, but none, according to Weed, occurred below that level. The data at hand are insufficient to prove whether this decrease in the grade of the ore in depth is due to secondary enrichment or to primary vertical distribution; the facts seem to point to a combination of both processes.

The surface ore now being taken out on the Nine Hour claim is thoroughly oxidized. It shows considerable azurite, together with oxides of iron and manganese in a quartz gangue, and is rich in fine gold, although this is not visible. The primary sulphides in the Drumlummon ore are tetrahedrite and chalcopryite in rather sparse amounts. Pyrite, galena, and sphalerite are rare. The bonanza ore formerly worked doubtless contained silver sulphantimonides, such as pyrargyrite, but tetrahedrite (variety freibergite) appears to have been the most important constituent. The gangue material is a fine-grained saccharoidal white quartz, in places so dense as to resemble porcelain. The texture is rather drusy and vuggy, and the vugs are lined with quartz, calcite, and dolomite crystals. Fragments of altered wall rock are common in the quartz. For example, good ore from the 1,000-foot level consists essentially of angular fragments of wall rock cemented by calcitic quartz of drusy structure; sparse chalcopryite is the only visible metallic mineral. Calcite, somewhat ferriferous and manganiferous, is prominent in various parts of the mine, and shows the lamellar habit and tetrahedral arrangement of the lamellæ so characteristic of the Marysville ores. Quartz that is pseudomorphic after calcite is found, but appears not to be as common as in other mines of the district.

Primary ore was seen in place on the 400-foot level, 50 feet south of the shaft. This ore is a somewhat calcitic quartz carrying tetrahedrite and chalcopryite; the adjoining hanging-wall rock is a firm,

¹ Op. cit., p. 107.

hard granite (or, accurately, quartz monzonite), which under the microscope proves to be highly calcitized and chloritized. At 150 feet north of the shaft the wall rock, which is here the banded hornstone, is extensively shattered by postmineral fracturing and leached by sulphate solutions. So thorough has this leaching been in places that all the bases have been removed, leaving a white rock of low specific gravity which consists essentially of silica. These altered wall rocks show an abundant development of manganese dendrites.

The calcitic nature of the primary ore of the Drumlummon vein precludes the possibility that secondary enrichment, whether of gold, silver, or copper, has extended downward to any considerable depth.

CRUSE MINE.

The Cruse or Bald Mountain mine, as it is known locally, together with the West Belmont mine, which is worked through the Bald Mountain adit, was the most active property at Marysville in 1911. Seventy men were employed until July 1, when a considerable reduction of the force took place. A 20-stamp mill is on the property; 70 per cent of the gold and silver is recovered on the plates, and the tailings go directly to a cyanide plant.

The mine is situated at the contact of the granite and hornstones, which form a capping resting horizontally on the intrusive granite. It is developed by three tunnels drifted on the vein; tunnel No. 1 is the working adit of the mine. The maximum depth reached anywhere in the mine is 500 feet. The vein trends east and west at right angles to the contact and dips 70° S. The two tunnels above No. 1 are in the hornstones; No. 1 commences in granite but encounters solid hornstone at 1,000 feet from the portal, although some minor masses of hornstones are inclosed in granite at some distance from the main contact. The 100-foot level below tunnel No. 1 is entirely in granite. The main ore shoot of the mine was in granite and was from 5 to 30 feet wide and 500 feet long. Along the strike, as seen in tunnel No. 1, the vein becomes abruptly narrow on entering the hornstone and tends to split and fork. The upper portion of the vein was inclosed in hornstones, which show pronounced evidence of oxidation and leaching by downward-moving solutions. The ore shoot did not come to the surface through this highly altered zone, and this fact, together with the decrease in value of the ore in depth, suggests that a secondary enrichment of gold has taken place.

The West Belmont vein, which is worked through the Bald Mountain adit, resembles the Bald Mountain vein. The ore consists of quartz intergrown with mangiferous calcite in large thin plates. The quartz in part is pseudomorphic after lamellar calcite; black oxide of manganese is more or less common, and the ore is therefore like that characteristic of the Marysville district.

BELMONT MINE.

The Belmont mine, situated on the east slope of Mount Belmont, has been one of the largest producers, but was idle during 1911 and not accessible. According to Barrell,¹ the mine—

has been developed on a system of veins running in general at a high angle to the contact surface. What is known as the main or south vein, running from west to northwest, forks to the west into two main branches which diverge at a slight angle, and the southern of these branches splits again. The north vein begins at a point about 100 feet north of the main vein, bearing at first northwest and then nearly north. This vein, as shown on the map of the second level, tapers out into a fork at the east end and passes into a barren fault to the northwest. The dip of the vein is toward the main vein at an angle of 70° to 75°. The veins are very short, and the ores are found only from the fourth level to the surface. They do not continue across the large dike or porphyritic hornblende-quartz diorite which separates this arm of hornstones from the main sedimentary body, but, as mentioned above, show a disposition to branch and taper out. Where the branches separate the country rock near the junction shows considerable brecciation with infiltration of quartz veinlets, and many such parallel quartz seams may be noted in the granite in association with the main vein, even where the latter does not branch. In the hornstones the vein matter is more sharply limited to the principal fissures, but these have an aggregate width as great as in the granite, indicating no greater opening of one than of the other. Within the mineralized zone the average aggregate width of vein quartz is estimated at about 3 feet per 100 feet of granite. On the fifth level the vein quartz shows widths of 3 to 5 feet but contains many opening vugs and is almost barren.

A series of east-west normal faults with dips to the south, later than the veins, in some places follow the strike and in others cut across the veins. These ore deposits have probably received considerable secondary enrichment in which the fault fissures have taken part.

Exceptional ore from the main level consists of fine-grained quartz which shows traces of lamellar structure and is traversed by manganese films. Some gangue material consists almost entirely of white lamellar calcite; other specimens show an equal admixture of calcite and quartz, and such material under the microscope reveals the remarkably perfect replacement of calcite by quartz. Comby amethystine quartz is also found.

BALD BUTTE MINE.

The Bald Butte mine is on the northwest slope of Bald Butte near the head of Dog Creek. A mill of 20 stamps belongs to the property, but is situated 1 mile downstream from the mine, necessitating haulage of the ore by teams.

The mine was operated continuously from 1890 to 1902, intermittently since that time, and was idle during 1911. The total production is two and three-fourths million dollars, of which approximately 90 per cent was recovered in the bullion and 10 per cent in the concentrates. The average yield on the plates was \$10.11 a ton and the

¹ *Geology of the Marysville mining district, Mont.*: Prof. Paper U. S. Geol. Survey No. 57, 1907, p. 109.

average fineness of the bullion was 753. The concentrates carried about 4 ounces of silver to each ounce of gold and averaged roughly 10 per cent of lead.

The workings comprised a number of surface pits and a series of tunnels, of which No. 2 has been the main working level in recent years. The extreme depth thus attained is 500 feet. Many of the drifts are inaccessible and no ore in place was seen. The workings are associated with a diorite porphyry dike, nearly vertical in attitude, and 60 feet wide, as shown in crosscuts. In places the dike is cut by a closely spaced system of veinlets, but this mineralized porphyry does not constitute ore, at least upon the lowermost level, where it assays under \$1. The veinlets are dense-textured aggregates of quartz and fluorite, showing a faintly banded structure, and commonly containing a small amount of fine flaky molybdenite. Shoots of ore were found alongside the dike in places and in the adjoining hornstone country rock on its northeast side. Here was found a highly irregular system of short narrow fissure veins. The "Knifeblade," so named because of its extreme narrowness, was extraordinarily rich in free gold. Associated metallic minerals were pyrite, galena, and sphalerite.

PENOBSCOT MINE.

The Penobscot mine, which is one of the best-known mines in the history of Montana on account of the extraordinary richness of its surface ore, lies near the head of Penobscot Gulch 2 miles southwest of the town of Marysville. The Penobscot vein as seen from the surface had a remarkably well defined hanging wall; the ore body, which swells and pinches, averaged 3 to 4 feet in width. The country rock inclosing the vein consists of the metamorphic hornstones of the Helena limestone cut by intrusions of diorite porphyry. Two parallel veins, known as the Eagle and the Leopard veins, which like the Penobscot dip 65° – 80° NW., lie in the footwall of the Penobscot vein; the Eagle at 250 feet, and the Leopard at 600 feet.

As shown on the stope map, ore was extracted from the Penobscot vein for 1,000 feet along the strike at the surface. The mine was developed to a depth of 500 feet, but the ore came principally from above the 300-foot level and largely from above the 200-foot level. The production was one and one-fourth million dollars. The ore rock is a porous manganiferous quartz, which in places carries lamellar calcite.

On the Eagle vein an incline was sunk 70 feet; the ore shoot yielded \$10,000, but gave out at 50 feet depth.

The present attempts to find ore in the Penobscot vein, which have continued in a small way during the last 10 years, consist of a tunnel 300 feet long (mainly along the vein) attaining a depth of 90 feet.

The face of this tunnel shows a lode of highly manganiferous and iron-stained porous quartz, which is said on competent authority to resemble the ore formerly found in the productive part of the Penobscot vein, but this material contains no gold. Another tunnel, which like the preceding is situated on the west end of the property, aims to tap the vein on the 300-foot level. The evidence from the history of the mine seems unfavorable to the probability of finding ore in depth; the geologic evidence, based on the presence of a highly manganiferous leached quartz, suggests that the gold may have been dissolved and carried to a lower level, and that therefore there is a possibility, at least worth testing, that ore may be found on the downward extension of the vein.

EMPIRE MINE.

The Empire mine and mill of 60 stamps, now idle, are situated on the west slope of Mount Belmont. The vein is said to be stoped out above the principal haulage level for a length of 1,500 feet, the extreme depth thus attained being approximately 400 feet. The country rock consists of the metamorphic phase of the Empire shale, which dips here 10° W. The vein trends N. 60° W. and stands vertical. The Whippoorwill is a parallel vein several hundred feet northeast of the Empire.

The ore now available is a sugar-textured white quartz full of vugs and devoid of metallic sulphides. It contains as a rule much lamellar calcite, which commonly forms plates of extraordinary thinness and diameter, some plates attaining a diameter of 6 inches.

PIEGAN-GLOSTER MINE.

The Piegan-Gloster, a consolidation of two adjoining properties, is situated 3 miles northwest of Marysville. The mine is opened by two tunnels on the vein, the upper one of which is now inaccessible. The lower tunnel, trending N. 25° E., is 1,200 feet long.

The mine is situated near the northwestern margin of the Marysville stock and the country rock is quartz diorite, but the contact-metamorphic hornstones are found near by. The vein as seen in the lower tunnel dips 60° E. and averages 3 feet in width. Some post-mineral movement has taken place along the walls, but the ore is generally frozen to the quartz diorite. The gangue is mainly quartz with some calcite. The quartz, which in places is amethystine, commonly shows large vugs lined with coarse crystals; in places also it displays the lamellar structure and tetrahedral habit so characteristic of the replacement of the calcite of the district. At the face of the tunnel the vein narrows to 1 foot of massive quartz containing small streaks of pyrite. Fragments of the diorite wall rock up to 6 inches in diameter are common in the vein.

The Gloster is stated to have yielded a considerable output in former years, the ore having been derived from a shoot 800 feet long, 600 feet deep, and from 3 to 12 feet wide.¹ The Piegan part of the property was systematically explored during 1906, and a winze 750 feet from the portal of the lower tunnel was sunk to a depth of 750 feet, but the mine was idle during 1911.

STRAWBERRY MINE.

The Strawberry mine lies 3 miles southeast of the town of Bald Butte and near the head of the gulch on the east side of Greenhorn Mountain. The developments consist of an inclined shaft sunk on the vein, a drift at 120 feet vertical depth, and a crosscut tunnel from the surface on the mill level. A 10-stamp mill stands on the property.

The vein, which strikes north and south and dips 60° W., is situated along the faulted contact of diorite and dark Marsh shale. It ranges in width from 3 to 15 inches. On the hanging-wall side it is separated from the diorite by a narrow seam of gouge, but is frozen to the foot-wall. The vein filling consists of quartz and calcite, both of which are lamellar in habit, forming a gangue material entirely similar to that of the veins at Marysville. The quartz is commonly of a delicate amethystine tint, and the lamellæ are so disposed as to form hollow tetrahedrons, which are incrustated internally with small quartz crystals. Small pieces of slate inclosed in the vein are surrounded by a radiating growth of quartz crystals.

The ore is said to yield upon the plates between \$30 and \$70 a ton in gold.

ELLISTON DISTRICT.

LOCATION.

Elliston is the first town on the Northern Pacific Railway west of the Continental Divide and is situated on Little Blackfoot River at an altitude of 5,000 feet. It is the shipping point of a large territory, but during 1911 little mining was in progress throughout this region.

The lime plant of the Elliston Lime Co. is situated 1 mile east of the town, the kilns standing alongside the railroad right of way. The raw material is quarried from the Madison limestone, which outcrops prominently here. The seasonal output of lime is reported to be 125,000 bushels of 80 pounds.

GEOLOGY.

The rocks in the immediate vicinity of Elliston consist of an apparently conformable succession of limestone, quartzite, and sandstone, striking north and south and dipping westward at an angle of 20°. They range in age from Carboniferous to Cretaceous. The lowest

¹ Rept. Montana State Inspector of Mines, for 1905-6, p. 109.

formation is the Madison limestone, well exposed 1 mile east of Elliston. This is overlain by the Quadrant quartzite, consisting predominantly of a dense massive quartzite, near the top of which occurs a bed of high-grade phosphate rock. The Quadrant quartzite is succeeded concordantly by the Ellis formation of Jurassic age, which is highly fossiliferous through a thickness of 50 feet. Above these rocks come several hundred, possibly a thousand, feet of cross-bedded sandstone, the upper portion of which is doubtless of Cretaceous age. Near the west end of the town the quartzite of the Quadrant formation is brought up again by a fault, but disappears within a short distance beneath the rhyolites that are prominent along the valley of Little Blackfoot River west of Elliston.

Rhyolites are present in considerable volume southwest of Elliston and persist on the flanks of the mountains up to an altitude of 6,200 feet. Some of these rhyolites differ considerably from the rhyolites common throughout the rest of the region; one of these is especially noteworthy because of its marked characteristics. It is a snow-white porphyry carrying as its sole porphyritic constituent large scattered phenocrysts of smoky quartz. Breccias of this rock are common. With the rhyolites are associated various basaltic rocks, among which a black glistening variety carrying large amber-colored phenocrysts of plagioclase is most prominent.

Tertiary lake beds underlie an extensive area west and northwest of Elliston. According to Douglass the lake beds north of Avon, which is 9 miles west of Elliston, are very probably of lower Oligocene age. At the mouth of Snowshoe Creek auriferous gravels rest on an eroded surface of lake beds.

Well-rounded gravels, presumably of Pleistocene age, occur 600 feet above the river in the vicinity of Elliston, but their origin was not investigated. A few miles southeast of the town extensive morainal deposits, as indicated by the pitted plain structure, are spread over the broad valley of Little Blackfoot River. These deposits, lying at an altitude of 5,000 feet, are the lowest glacial deposits found anywhere in the region considered in this report.

DESCRIPTIONS OF MINES.

JULIA MINE.

The Julia mine, the property of the Montana-Clinton Copper Mining Co., is situated 8 miles south of Elliston at an altitude of 6,600 feet on the west side of Telegraph Creek. This is a comparatively recently discovered property. It is developed by a shaft 210 feet deep. The vein is inclosed in granite and as a rule lies between exceedingly well defined walls, although the ore does not, except in a few places, fill the entire vein. The course of the vein is slightly south of east and the dip is 80° S. As seen on the 200-foot level,

which is 150 feet long, the vein swells and constricts abruptly, ranging in thickness from 6 inches to a maximum of 5 feet. The sulphides reach 2 or 3 feet in thickness. The granite or quartz monzonite inclosing the vein is firm and unaltered up to the walls, being only slightly pyritized for about 1 foot from the vein; that within the vein is greatly altered and along the walls there is considerable soft sticky gouge due to postmineral movement.

The ore consists of a heavy sulphide mixture of galena, sphalerite, pyrite, and tetrahedrite, associated with subordinate quartz. The texture in places is rather drusy, vugs lined with quartz crystals being common. Tetrahedrite indicates a high content in silver. Sulphides consisting predominantly of pyrite, which commonly occurs in large well-crystallized pentagonal dodecahedrons, are discarded as valueless. The ore is stated to carry 60 ounces in silver with small amounts of lead and copper.

The surface ore is said to carry much gold, but the amount has decreased with increasing depth. The silver is said to have increased. As a rule, however, there is little evidence of oxidation or enrichment.

EVENING STAR MINE.

The Evening Star mine, better known as the Big Dick, lies 6 miles due south of Elliston on the summit of the mountain on the south side of Little Blackfoot River. The altitude is 7,000 feet. This property was idle during 1911.

The country rock is a coarse andesitic breccia, apparently bedded; the strike is N. 50° E. and the dip 20° NW. It is much jointed so that determinations of strike and dip of bedding are likely to be unsafe. The ore deposit is said to be a blanket vein developed by a shaft 300 feet deep and is said to dip north at a low angle. The ore carries galena, pyrite, sphalerite, and arsenopyrite in a quartz gangue; some of the quartz contains numerous large columns of black tourmaline intergrown with pyrite. The ore is reported to have been high grade, carrying as much as 3 ounces of gold a ton. During 1906 a gold-silver-lead ore was shipped to the East Helena smelter and a production was maintained until 1910. The deposit was worked out to the west end line; during 1911 the lessees were engaged in sinking a shaft near this end line on the adjoining claim, which is one of a group known as the Finnish or Weston group. It was expected that the Big Dick vein would be struck at a depth of 150 feet.

TWIN CITY MINING & MILLING CO.'S MINE.

The Twin City Mining & Milling Co.'s property is situated 8 miles south of Elliston at an altitude of 6,800 feet, on the east side of Telegraph Creek. It is developed by a shaft 85 feet deep with a crosscut at the bottom 21 feet long, but these were under water at the time of

visit. The vein is inclosed in granite, trends N. 70° E., and is 18 feet wide. It is reported that 8 feet of the lode adjoining the footwall averages \$3.60 a ton, the product being gold, silver, copper, and lead. The material on the dump resembles in part the ore at Rimini, being a black tourmaline-bearing quartz ore. Some strong tourmalinic lodes have been uncovered in the vicinity of the shaft, but they have not been found to carry any valuable constituents.

ONTARIO MINE.

The Ontario mine, which has the reputation of having been one of the largest producers in the Rimini district, is situated near the head of Ontario Creek, a branch of Little Blackfoot River. The main developments consist of a crosscut tunnel 800 feet long, from which is sunk a shaft 320 feet deep. These workings were inaccessible during 1911. The country rock is granite, and the ore, as shown on the dumps, consists of pyrite, sphalerite, and galena, inclosed in quartz.

MONARCH MINE.

The Monarch mine lies on the north flank of Bison Mountain at an elevation of 7,250 feet. Geologically it is situated near the intrusive contact of the quartz monzonite and the overlying andesites. The ore minerals are galena, blende, pyrite, and arsenopyrite in quartz.

BLUE BELL MINE.

The Blue Bell mine, although long idle, is worthy of description here on account of its unusually interesting geologic features. The mine is situated 1 mile southeast of the west portal of the Mullan tunnel. The developments consist of a shaft, a number of surface cuts, and a tunnel about 175 feet below the collar of the shaft. It is reported that some rich copper ore was shipped from the mine.

The country rock is a monzonite containing numerous large porphyritic orthoclase crystals. The nearest intruded rock is a mile distant and consists of Madison limestone. The ore material is mainly fine-grained garnet rock carrying disseminated molybdenite and pyrite. There is also much porous rock composed of large euhedral garnets coated with secondary minerals. An open cut 200 feet from the shaft shows clearly the geologic relations of the ore to the inclosing country rock. In this open cut the lode is about 12 feet wide, and the filling consists of garnet rock inclosing a few irregular thin masses of monzonite. These masses are in fact ungarnetized residuals of monzonite. Veinlets of garnet traverse the monzonite exactly as veinlets of quartz and tourmaline do in the ordinary forms of mineralization throughout the region. In the vicinity of fine cracks near the garnetized zone the plagioclase feldspars of the monzonite have been converted solidly to brilliant yellowish-green aggregates of epidote, —

and the rock is thus rendered strikingly porphyritic. The thin veinlets of garnet are commonly bordered by a white band of altered monzonite, contrasting markedly with the normal dark-gray color of the monzonite. When examined microscopically, the white rock adjoining the garnet veins is found to consist essentially of garnet and scapolite, with subordinate amounts of epidote, orthoclase, plagioclase, pyroxene, quartz, and apatite. Some of the massive garnet rock is found under the microscope to consist predominantly of garnet, with which is associated some monoclinic pyroxene, suggestive of hedenbergite, and a small amount of sericite. The garnet is a dark-brown variety, whose index of refraction exceeds 1.79.

All the features of this deposit suggest that it is a vein of garnet in the monzonite. It is possible that it represents a highly metamorphosed inclusion of limestone from the roof of the batholith, but the field evidence seems to be against this supposition. Whatever explanation is adopted, the phenomena here show conclusively that the garnet molecule is able to migrate and form veinlike deposits under the influence of chlorine-bearing solutions.

RIMINI DISTRICT.

LOCATION.

Rimini lies at an altitude of 5,200 feet, 14 miles by air line southwest of Helena. It is situated on Tenmile Creek, which flows in a deep gorge just above the town, between Red Mountain on the east and Lee Mountain on the west. The surrounding country is of high relief, so that mine development is favored to an unusual extent by the ease and advantage with which adit tunnels can be constructed.

Rimini is the terminal point of a branch of the Northern Pacific Railway from Helena; owing to the present low state of the mining industry a semiweekly service only is maintained. A considerable mining territory is tributary to Rimini; this was formerly, and is occasionally now, known as the Vaughn mining district.

GEOLOGY.

The prevailing country rock is coarse-grained granite, technically a quartz monzonite, composed of plagioclase, orthoclase, quartz, biotite, and hornblende. It is of uniform appearance and, as shown by chemical analysis of material from the Frohner and Valley Forge mines, coincides in composition with the general rock of the Boulder batholith. A considerable body of aplite extends along the ridge from the Peerless Jennie mine to Red Mountain, where it is covered by rhyolite.

Pregranitic rocks, represented by the andesite-latite series, occur 2 miles below Rimini and extend westward across the Continental

Divide. On the summit a flow-streaked biotite latite is well exposed, and masses of diorite porphyry are common. Farther south on the divide is a small patch of profoundly tourmalinized andesite. The distribution of these pregranitic rocks suggests that although bare granite is the dominant surface rock in the Rimini district, the present surface is neither far removed nor much below the under surface of the cover beneath which the granite was intruded. The greatest depth is indicated at Rimini, possibly 2,000 feet.

Rhyolites are a conspicuous element in the geology of the district. They form the capping of Red Mountain and of Lee Mountain, extend southward along the high summits, and form the bedrock of the well-known "porphyry dike" country. Those of Red Mountain display a great variety of color and texture, but nearly universal features are flow streaking, abundant phenocrysts of smoky quartz, and phenocrysts of sanidine, commonly opalescent. The rhyolites are mainly lithoidal porphyries but include some obsidian and some breccias.

ORE DEPOSITS.

Two periods of mineralization are recognizable at Rimini: An older or late Cretaceous and a younger or late Tertiary period. The ore bodies of the first period are auriferous silver-lead deposits inclosed in granite. The principal ore mineral is galena, accompanied by sphalerite and pyrite. Most of the lodes are notably tourmaline-bearing, and the characteristics of these deposits have been described on pages 46-51 under the heading "Tourmalinic silver-lead deposits." It is to be noted that at Rimini tourmaline is usually called hornblende.

Among the deposits of this kind may be enumerated the Lee Mountain, Valley Forge, East Pacific, Lady Washington, John McGrew, and Armstrong on Minnehaha Creek. Others, such as the Election, show only feeble tourmalinization, and still others, such as the Eureka, show no tourmalinization, so far as this study was able to determine. These probably represent the nontourmalinic phase of the same mineralization, comparable in its effects to that which has altered the footwall of the Valley Forge mine.

Sulphide ore is encountered at shallow depths beneath the carbonate zone; in the Valley Forge mine, for example, at 40 feet. Although the relief of the district is large and abrupt, water stands near the surface. At an altitude of 6,250 feet water stands in the East Pacific shaft at 50 feet depth, although the bed of Tenmile Creek, less than a mile away, is 1,000 feet lower.

Mining activity was at a low ebb during 1911. Yet it seems probable that at least some of the mines which have been important producers in the past may again become productive upon systematic

exploration and development. There seems to be no reason against the possibility that as good bodies of ore may be encountered in depth as have been found on the upper levels. Further, as has already been pointed out, the ore occurs in chambers scattered through zones of tourmalinized and sericitized granite; it follows, therefore, that any such zone of profound alteration should be explored thoroughly along the strike and equally thoroughly across the strike by crosscuts driven across the full width of the ore-bearing zone.

The Tertiary deposits consist of low-grade disseminated gold ore inclosed in the rhyolites resting on the eroded surface of the granite. The most prominent is the "porphyry dike" property, near the head of Tenmile Creek. The "dike," however, is not a dike but a series of surface flows of rhyolite lying on the granite. The practical importance of this distinction is of course obvious: A dike has an indefinite extension downward, whereas the rhyolite flows form a capping of definite thickness, being terminated in depth by the granite floor on which they rest. The rhyolites are altered and impregnated with gold along small fractures, the whole mass constituting a low-grade ore said to carry several dollars to the ton. More details are given in the special descriptions.

DESCRIPTIONS OF MINES.

VALLEY FORGE MINE.

The Valley Forge mine is situated on the flank of the mountain just east of the town of Rimini. It is developed by a series of drift tunnels, the lowest of which is at an altitude of 5,800 feet; in this a winze was sunk 100 feet deep. The ore bins at the mouth of the lowest tunnel are connected with the Northern Pacific Railway by an aerial tramway. The extreme depth attained below the surface is approximately 325 feet. A tunnel was commenced from the level of the town of Rimini which will give an additional depth of 600 feet on the lode; the length required is estimated to be 1,385 feet, but as yet only 300 feet have been completed.

All ore above the main tunnel has been stoped out. During the early part of 1911 three men were employed getting out carbonate ore from the outcrops. This was shipped to the East Helena smelter and is stated to have carried \$6 in gold, 12 ounces in silver, and 7 per cent lead, but this is low-grade ore. Higher-grade material is said to carry as much as \$11 in gold.

The total production of the mine is about \$200,000, the ore ranging in value from \$15 to \$30 a ton in gold, silver, and lead. The gold exceeded the silver in value and the lead ran as high as 40 per cent.

The general country rock at the mine is granite, although just to the north across the gulch is a small patch of flow-streaked rhyolite.

The lode trends east and west and dips 80° S., thus conforming with the general trend of the veins at Rimini. It averages 4 feet in width. The footwall is commonly well defined and consists of sericitized granite impregnated with pyrite, galena, sphalerite, and arsenopyrite, as described elsewhere in detail in this report. The hanging wall consists of quartz-tourmaline rock or so-called black quartz, which in places reaches 6 feet in thickness. This carries a small amount of pyrite, some sphalerite, and galena; locally all three of these sulphides are intergrown.

The commercial ore consists of an aggregate of galena and pyrite which is associated with some sphalerite and rarely some chalcopyrite. The ore occurs in shoots lying beneath the hanging wall of black quartz-tourmaline rock. The shoot on the lowermost tunnel, No. 3, was 350 feet long, but for 450 feet from the portal the lode or mineralized zone, although well defined, was barren.

Two hundred feet south of the Valley Forge lode is a vein of heavy jasperoid which has been opened by prospect pits to some extent. It is said to carry gold in places. The ledge is formed along a brecciated zone of tourmalinized granite. Analysis by J. G. Fairchild of the heavy red jasperoid material shows that it contains 43.60 per cent ferric oxide, representing total iron, 49.06 per cent silica, and 6.38 per cent water.

LEE MOUNTAIN MINE.

The Lee Mountain mine is situated on the west bank of Tenmile Creek at Rimini. The lode was discovered in 1864 by John Caplice and the claim was staked under the old Montana law that allowed the preemption of claims 2,200 feet long and 100 feet wide. The mine was opened by a series of drift tunnels, the lowest of which, driven 30 years ago, is approximately 850 feet long and attains a depth of 600 feet. The present lessees contemplate sinking a shaft to a depth of 200 feet below the level of this tunnel and drifting eastward under the bed of the creek, where, according to report, a good body of ore was exposed before the stream bed was covered with rock débris.

The production of the Lee Mountain mine is conservatively estimated as \$1,500,000, of which \$750,000 is authenticated by smelter returns.

The ore occurs in chambers distributed through a zone about 50 feet wide. The general trend of the ore-bearing zone is N. 85° E. and the dip 80° S. A ledge of black tourmaline-quartz rock, ranging up to 8 feet in thickness, accompanies the ore-bearing zone. The ore makes in the adjoining highly sericitized granite and consists of a mixture of galena, sphalerite, pyrite, and subordinate arsenopyrite, with some tetrahedrite. More or less altered granite is mixed with the sulphides. Considerable postmineral movement has affected the ore bodies and in consequence much soft sericitic gouge is present.

Ore recently developed at the face of the lowest tunnel yielded, as shipped, \$2 to \$4 in gold, 20 ounces of silver, and 10 per cent lead; it also carried 8 per cent zinc. This ore is a mixture of primary sulphides and indicates that the unoxidized ore of the deeper workings is of payable grade. It is probable that the ore worked formerly consisted largely of oxidized material, from which, as shown by some sacked ore still remaining, the zinc had been entirely leached out.

JOHN MCGREW PROSPECT.

The John McGrew claim was being developed under bond during the summer of 1911. It is an old property, having been located over 30 years ago. Developments consist of a drift tunnel within which a winze was sunk 35 feet; at the bottom of this a drift along the vein was being driven.

The lode is inclosed in granite and the ore makes abruptly and capriciously along a ledge of black quartz-tourmaline rock. In the bottom drift the lode is 18 inches wide and shows a banded structure. Along the hanging wall there is 3 inches of barren black tourmaline; this merges toward the footwall into a low-grade pyrite galena ore and becomes quartzose on the footwall. Barren gray quartz, 3 inches wide, rests directly on the footwall. A small amount of iron-stained gouge is found along the walls.

PEERLESS JENNIE MINE.

The Peerless Jennie mine is situated near the divide at the head of Tenmile Creek at an altitude of 7,500 feet. It was formerly a considerable producer of silver-lead ore, but has been idle for many years. The vein consists of a crushed zone in granite about 6 feet wide and dipping 70° N. The underground workings comprise a crosscut tunnel 240 feet long and several hundred feet of drift along the vein. The adit level attains a depth of approximately 200 feet from the surface and the ore is stoped out to the shaft level above. At the face the vein consists of crushed granite, containing locally small seams of quartz. The granite adjoining the vein is thoroughly sericitized and impregnated with cubical pyrite. The ore on the dump is chiefly pyrite embedded in quartz, associated with sphalerite and in places with cerusite. The richest ore is said to have occurred in pockets of galena.

According to R. W. Raymond¹ the surface ores were extraordinarily rich; 50 tons averaged 900 ounces of silver to the ton and 200 tons averaged nearly 500 ounces.

PORPHYRY DIKE.

The summits of the mountains between Ruby and Monitor creeks at the head of Tenmile are capped by a series of rhyolite flows and

¹ Statistics of mines and mining in the States and Territories west of the Rocky Mountains, 1874, p. 362.

interbedded tuffs and breccias. This rhyolite capping is known as the porphyry dike, and the whole area throughout which it occurs has been covered by mining claims. That this rhyolite is auriferous is indicated by the fact that old placer workings extend to the very summit of the range, where the streams flowed on a rhyolite bedrock.

At 7,500 feet altitude is a large pit about 50 feet in diameter and averaging 40 feet deep, from which ore was taken out and treated in a 10-stamp mill until the work was stopped by the water company that furnishes the municipal supply for Helena. A tunnel has been driven approximately 125 feet below the pit and is said to be 1,400 feet long. It commences in the granite on which the rhyolites rest.

The country rock as exposed at the pit from which the ore was quarried is a strongly flow-banded and laminated rhyolite; the flow bands are steeply tilted at angles ranging from 60° to 90° and are convoluted and irregular in direction. The rhyolite is remarkably full of lithophysæ (stone roses), ranging in size from a fraction of an inch to several inches. At one place there is a width of 20 feet of lithophysal rhyolite. The walls of the lithophysæ are coated with quartz crystals, as are also the pores and cavities in the flow bands of the rhyolites. In places the quartz has grown exceedingly coarse, some prisms an inch in diameter having been formed. The rhyolites are generally of white chalky appearance and in places are interlaced with quartz veinlets one-tenth of an inch in thickness. They are considerably less porphyritic than the varieties of rhyolite prevailing in the surrounding region, but carry sporadic phenocrysts of quartz. Under the microscope they exhibit the usual features of rhyolites, except that they have been considerably sericitized and that much kaolin is present.

The rhyolites show some limonite derived from the oxidation of pyrite crystals. They are traversed also by limonite-stained fractures, which are said to be particularly favorable places for the occurrence of gold. As a rule, however, gold is not visible to the eye. The deposits have been extensively sampled, both by surface work and by diamond drilling, and are said to show a gold tenor of several dollars to the ton.

In addition to the ore taken at the pit described above, considerable ore was mined at the pits on the property known as the Pauper's Dream. The rock exposed in these pits consists of rhyolite tuff-breccia of kaolinized appearance; this ore is reported to have milled \$2 a ton in gold.

HELENA DISTRICT.

HISTORICAL SKETCH.

Helena, the capital of Montana, is a city of 12,515 population, situated in Lewis and Clark County at an elevation of 4,100 feet. It was founded in 1864 as a result of the discovery of the Last Chance

placer by a party of prospectors who had turned back from the Kootenai stampede. In the fall of the same year lode gold was discovered on the divide between Oro Fino and Grizzly gulches, 5 miles south of Helena. This was the famous Whitlatch-Union lode which, according to report, has produced \$6,000,000 to date.

The gold placers were soon exhausted, but a considerable quartz mining industry sprang up south of Helena, at Park and Unionville. The earliest estimate on record concerning the output of the Last Chance placer is that by Vom Rath in 1883, who gives the output as over \$10,000,000;¹ succeeding estimates, by Bancroft in 1889, place the output at \$16,000,000;² by Swallow in 1890, at \$30,000,000,³ and by recent writers at \$35,000,000. The estimates have thus increased enormously, although placer mining had long ceased to exist previous to 1883.

During 1911 little mining of any kind was in progress. The production of precious metals, mainly gold, in 1910 was about \$15,000.

GEOLOGY.

The distribution of the geologic formations in the vicinity of Helena is shown on the accompanying map (Pl. VII) on the scale of approximately 1 mile to the inch. This map was prepared by W. H. Weed and his assistants and shows the geology of the area in far greater detail than is shown on Plate I.⁴ The following text (pp. 86 to 98) is taken, with few changes, from an unpublished report by Mr. Weed.

SEDIMENTARY ROCKS.

GENERAL FEATURES.

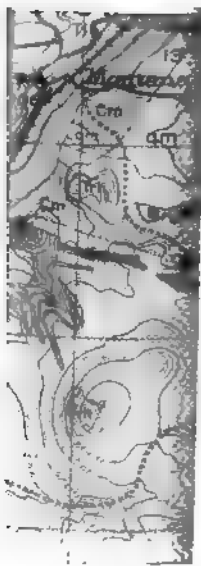
The various sedimentary formations recognized in the Little Belt Mountains and in the ranges near Livingston can in a general way be correlated with the sedimentary series at Helena. The series differs, however, somewhat in detail and no sharp discrimination of the formations by means of fossil remains is as yet possible, owing to lack of evidence. Fossils are not abundant. The Cambrian and the Carboniferous limestones usually carry shell remains, but in general the rocks are barren and over a considerable area are altered, the limestones being marmorized by contact metamorphism due to the granite intrusion. This contact metamorphism is especially notable in the Mesozoic rocks, whose determination as such is based on

¹ Zeitschr. Deutsch. geol. Gesells., vol. 26, 1884, p. 639.

² History of Washington, Idaho, and Montana, 1890, p. 721.

³ Rept. Montana State Inspector of Mines for 1890, Helena, 1891, p. 37.

⁴ In preparing the drawing of this map for publication here, the area originally shown as quartz monzonite, granite, granite porphyry, and diorite have been given the general symbol of quartz monzonite; the area of igneous rock east of Lenox, originally shown on the map as granite porphyry and described in the text as rhyolite porphyry, has been marked with the diorite symbol, in conformity with the results of the present investigation.



CINITY

stratigraphic sequence and character—fortunately satisfactory evidence in this case. The formations are mapped according to the detailed tracing of distinctive and easily recognizable beds by L. S. Griswold. The boundaries adopted for intervening formations are somewhat arbitrary but have been checked up or connected at several points and are substantially correct.

Great difficulty was experienced in attempting to define the subdivisions of the Algonkian. The various formations of the Belt series are as a whole individualized, but they are extremely difficult to define in mapping and the boundaries on the map are not closely accurate.

Thicknesses were determined by two carefully measured sections, one on Mount Helena and in its vicinity and the other near Unionville, many partial sections being measured elsewhere. No place was found where the whole sequence of beds was satisfactorily exposed, but the section is correct so far as determinable along the line measured, additional information being derived from work near by.

For the reasons already stated no distinction could be made in the Mesozoic. The Jurassic is believed to be present, as it is well developed at various points not far distant on every side, but careful examination furnished no satisfactory proof of its presence here. The same reason explains the lack of subdivision in the Cretaceous.

ALGONKIAN SYSTEM.

Distribution and subdivision.—The oldest rocks of the Helena district are those of the Belt series, of Algonkian age. The series, where fully developed, consists of eight formations, each well defined as a whole, but grading into one another, so that the subdivisions are not sharp and can not be adequately separated in mapping in this region. The series is named from its occurrence in the Big Belt Mountains, where it is typically developed and forms the core of the range. The rocks cover a large area in northwest Montana, extending northward into Canada. The following formations have been established by Walcott, who gives the thicknesses here stated:

	Feet.
Marsh shale.....	300
Helena limestone.....	2,400
Empire shale.....	600
Spokane shale.....	1,500
Greyson shale.....	3,000
Newland limestone.....	2,000
Chamberlain shale.....	1,500
Neihart quartzite.....	700

In the Helena district only the four uppermost formations are found, and the top of the Marsh shale has been eroded before the deposition of the Cambrian, so that the upper limit of the formation and its entire thickness are not known.

Spokane shale.—The oldest rock of the Helena district is the Spokane shale. It consists of massive and thinly bedded siliceous shales, usually of a deep-red color but passing in places into green and gray rocks, containing arenaceous beds which merge at times into sandstone. The formation is named from the Spokane Hills, 15 miles east of Helena, where it is finely developed. The rocks form low hills bordering the Prickly Pear Valley on the north and west.

Empire shale.—The Empire shale is a formation composed of massive-bedded, greenish-gray, well-banded, siliceous shales, showing color bandings of light and dark material and locally a marked knotty structure. The thickness is estimated by Walcott at 600 feet. The rocks are seen in the hills near the railroad from 2 to 3 miles west of East Helena. At this locality they consist of pale greenish-gray slates, with characteristic purple spots.

Helena limestone.—The Helena limestone is a formation composed predominantly of impure bluish-gray or gray noncrystalline limestone. The limestones occur in beds 1 foot to 6 feet thick and contain thin interbedded bands of gray siliceous shale, more rarely of green to purple clay shales. The limestones are ordinarily dark blue on fresh fracture but show a characteristic buff-colored velvety appearing surface on weathering. The upper beds have a rough surface, with a pale or blue-gray color, and resemble Cambrian rocks. These beds alternate with shale and form the ridges on the northwest foot slopes of Mount Helena.

The formation has no distinctive physiographic expression within the district, but its relatively massive bedding gives the limestone prominence on the slopes about the city.

The name was given the formation by Walcott from its typical occurrence about the city of Helena.

The formation is barren of fossils, though the oolitic character and the local presence of carbonaceous markings has led to the belief that they will ultimately be found. The estimated thickness of 2,400 feet in this vicinity is based on rough measurements, as it is impossible to find a satisfactory exposure of the entire formation for exact measurement. The formation covers a large part of the district, especially about the borders of the Prickly Pear Valley. So far as known the rocks are conformable to the formations above and below, and grade into them by intercalations of shale. The upper and lower limits are therefore not sharply definable. About a mile east of Helena the Marsh shale is wanting and the Cambrian quartzite rests directly on the eroded surface of the Helena limestone. Good outcrops are seen near the high school within the city limits.

On the north face of Mount Helena the Cambrian quartzite rests on dark-blue and dense limestones, weathering buff, and these rocks in turn rest on pink and buff-colored shales, which appear red in

most exposures and are included as part of the Helena limestone. These reddish shales contain numerous massive beds of white cherty limestone, forming reefs running obliquely across the slopes and extending downward within a few yards of the streets of Kenwood. The beds of limestone are 6 to 10 feet thick and in weathering and character resemble those of Paleozoic rocks. The same pink and buff-colored shales, with interbedded limestones, are seen in the gulch east of Lenox, the 4,350-foot knoll at that locality showing light-gray fine oolitic limestone with black grains in a white matrix.

Marsh shale.—The Marsh shale consists of red and yellowish-green shales and thin-bedded sandstones. According to Walcott, it is 250 feet thick east of Helena; on the north slope of Mount Helena it is reduced to 75 feet; and to the northwest it increases in thickness to 300 feet. The formation is cut out 1 mile southeast of Helena, but the shales reappear at a point 2 miles southeast of the city. The name is derived from Marsh Creek, in the vicinity of Marysville, Mont., where the formation is typically developed. It is also the predominant formation on the slopes of Greenhorn Mountain, near Marysville. It is seen underlying the Flathead quartzite on upper Main Street in the city of Helena, 165 feet of beds being exposed

CAMBRIAN SYSTEM.

Subdivisions and character.—The Cambrian rocks of the Helena region, as in the Little Belt Mountain region to the east, are divisible into seven formations. All these formations except the uppermost—the Yogo limestone—are of Middle Cambrian age; the Yogo limestone is of Middle Cambrian and Upper Cambrian age, according to Walcott. The Helena region shows the same alternations of quartzite, limestone, and shale recognized in the mountains to the east of the Little Belt region and southward to the Yellowstone Park; the formation names adopted for the Little Belt region will therefore be used in this report. These names are, from the basal formation upward, Flathead quartzite, Wolsey shale, Meagher limestone, Park shale, Pilgrim limestone, Dry Creek shale, and Yogo limestone. On the map the Flathead quartzite is discriminated and the rest of the Cambrian formations are shown undivided.

The line between the Cambrian and Devonian rocks was originally supposed to be the upper limit of a well-marked shale belt. This shale belt is persistent and well recognized and was in mapping regarded as the upper limit of the Cambrian. Later work, however, showed that the limestones lying above this shale also belong to the Cambrian, and it became necessary to draw a new line, based on stratigraphic evidence and the topographic relief but not checked by field observations; this line is not, therefore, free from error.

Flathead quartzite.—The Flathead quartzite, the lowest formation of the Cambrian system, consists of a hard, fine-grained, massive

quartzite varying to grayish-yellow to gray sandstone. The lowest stratum in places is pebbly, grading into a conglomerate at the base. The bedding planes range from a few inches to a few feet apart and faint lines of sedimentation are seen. The rock is jointed by sharply cut planes. Higher up in the formation thin beds of gray-brown mottled and green micaceous shale are found locally, increasing in thickness toward the top. The pebbles in the basal bed vary in character from place to place and consist predominantly of the material derived from the immediately underlying beds. As mentioned elsewhere, this quartzite is in most places apparently conformable to the Algonkian, but there is a slight angular unconformity observable east of Helena, and the Marsh shale is in places cut out, so that the quartzite rests directly upon the Helena limestone. The only fossils recognized are scolithus borings. The total thickness of the Flathead quartzite in the Helena district is 300 feet. The formation is easily recognized in the topography of the area, as the resistant nature of the beds causes them to form low foothill ridges, which are prominent on the slopes of Mount Helena, and as the cap reef on the mountain ridge running southward from that peak.

Wolsey shale.—The Wolsey shale consists of micaceous and calcareous gray to greenish shales, which contain small oval and flat concretions of limestone, grading in places into thin and very irregular plates of limestone. Trilobite and shell remains of Cambrian types occur abundantly along the contact between these shales and limestones. The rocks are in few places well exposed, owing to their soft and crumbly nature, but their position is recognizable by the ravines cut in them or, on the mountain slopes, by their forming a more gentle angle between the limestone bluffs above and the quartzite ridges below. They have a thickness of about 420 feet.

Meagher limestone.—The Meagher limestone is composed of light-gray to bluish limestones, which are shaly near the base but grade into alternating beds of massive dark-colored and flaggy white limestones, and these into thinly-bedded dark-purple to blue fossiliferous limestones, forming the top of the series. In other regions the rocks are pebbly, but this character is not conspicuous in the Helena district. The rocks have an estimated thickness of 400 feet. They form the characteristic bluffs on the north face of Mount Helena, extending from the gentle slopes formed by the Wolsey shale upward almost to the very summit of the mountain. The rocks are also seen in the bold cliffs below the east side reservoir. Fossil remains occur, but no collections were made.

Park shale.—The Park shale consists of earthy and micaceous dark-gray to green or purple shales. The rocks are not well indurated and crumble readily, so that very few good exposures are seen. A partial section is exposed in the quarry near the upper part of the

city of Helena, and shows the formation to contain lavender or pinkish beds, grading through green shales to a grayish earthy shale carrying an abundance of small fossil shells, identified as *Obolella*. The upper portion contains limestone lenses in a jaspery shale, which grades downward into a dense cherty rock resembling hornstone. This shale has an estimated thickness of 150 feet. It forms the flat bench on the summit of Mount Helena, between the apex and the northern cliffs, and covers the ridge followed by the trail.

Pilgrim limestone.—The Pilgrim limestone consists of massive beds of bluish to dark-gray limestones. The lowest bed is a dark-colored crystalline rock, mottled with yellow and dark-gray spots; its peculiar coloration and massive character are characteristic of the limestone throughout Montana. This bed of mottled limestone is overlain by light-gray to white noncrystalline limestone, used for making quick-lime in the Grizzly Gulch kilns. No fossils have been found in the mottled limestone, but its position and lithologic character correlate it with the "Mottled" limestone of the Yellowstone Park folio. This formation occurs on the very summit of Mount Helena, where it forms the uppermost bed of the gentle syncline sweeping down the southeastern side of the mountain. It is also seen in bluffs above the East Side reservoir, and forms a low cliff extending up Oro Fino Gulch for 2 miles above the city, the relief being due to the crumbly nature of the Park shale in which the gulch is being eroded. The mottled beds are 150 feet thick and are overlain by white limestone, which is included in the formation. The total thickness of the formation is 317 feet.

Dry Creek shale.—The Dry Creek shale consists of light-colored brownish-yellow, red, and pink shales and calcareous sandstones. The formation is well exposed in few places but can be recognized by its topographic relief, as it forms sags in the high ridges and ravines on the mountain flanks. No fossils have been found in the shale. It is correlated on the basis of lithology and stratigraphic position with the Dry Creek shale of the Threeforks and Little Belt regions. The thickness is estimated at 40 feet.

Yogo limestone.—The Yogo limestone consists of light-colored, thin-bedded limestones, with crinkly bands and films of jasper, in many places composed of limestone pebbles held in a glauconitic matrix. The formation corresponds to the so-called "Pebbly" limestone of the Threeforks folio. It has a thickness of 175 to 450 feet. The jaspery flaggy limestone forms prominent buttress exposures along the east side of Oro Fino Gulch above the city.

DEVONIAN SYSTEM.

The Devonian period is represented by two formations, the Jefferson limestone at the base and the Threeforks shale at the top. On the map these formations are not separated.

Jefferson limestone.—The Jefferson limestone, the lower of the Devonian formations, consists of a series of limestones, characteristically dark colored, but includes also some light-colored beds. The dark beds have a characteristic granular structure, are commonly mottled by light-colored patches due to metamorphosed corals, and are quite fetid when struck with a hammer. The assignment to the Devonian is based on fossil remains found in other areas, as the rocks within the Helena district have not yielded any identifiable fossils. The lowest beds are dark colored, almost steely in luster and texture, and usually form a bluff or ledge that rises abruptly above the more fissile Yogo limestone. The buff-colored argillaceous shales which overlie the limestones have been included in the Jefferson, but they may belong to the Threeforks shale. The total estimated thickness of the Jefferson limestone is 243 feet.

Threeforks shale.—The Threeforks shale varies somewhat in the different parts of the Helena district. It is essentially composed of black shale and alternating beds of limestone; it contains brachiopod remains, which correspond to those identifiable elsewhere as Devonian species. It corresponds in position to the formation in the Threeforks quadrangle known by this name. The uppermost bed of the formation is 15 feet thick, consisting of fine-grained black carbonaceous shale. This rests on light-colored fossiliferous calcareous shales that grade downward into earthy shales with interbedded bands of quartzite, the total thickness being 270 feet. The rocks are seen on the ridge west of Grizzly Gulch about $1\frac{1}{2}$ miles from Park. At this locality there is a basal bed of shale 40 feet thick, capped by 186 feet of calcareous argillite overlain by 56 feet of black shale. The formation is well exposed only on the high ridges, where it forms low saddles between limestone knobs. In the gulches cut in these rocks exposures are poor and more than a few feet of the beds can be found at but few places.

CARBONIFEROUS SYSTEM.

Distribution and character.—The Carboniferous system is represented in this region by a basal formation consisting of a mass of limestones characterized by lower Carboniferous or Mississippian fossils, to which the name Madison limestone has been applied. This limestone is overlain by a formation, essentially quartzitic, which is correlated with the Quadrant formation of the Yellowstone Park, Threeforks quadrangle, and other areas in Montana. The rocks are well exposed and cover a considerable portion of the mountain area in the southern part of the district. As a rule they are readily distinguished from the soft Mesozoic rocks which overlie them, but in this region contact metamorphism has so altered the Mesozoic rocks that they are as hard and resistant as those of the Carboniferous period.

Madison limestone.—The Madison limestone in the eastern ranges of the State has been subdivided by Weed into three members, to

the lowest of which he gave the name Paine shale, to the middle the name Woodhurst limestone, and to the upper the name Castle limestone. All these subdivisions can be recognized in a general way in the Helena district. The lowest member consists of thin-bedded impure bluish limestones, which carry crinoid stems and other fragmentary fossil remains. A very persistent bed is characterized by black needles of tourmaline, and as this bed occurs near the base of the formation it is quite useful in mapping the limits of the Madison. This member grades upward into the well-bedded limestones of the middle member, which forms the steep slopes and well-marked cliffs throughout the southern part of the district. The rock is light gray to dark gray and the beds are separated by partings of impure shaly material, which break into angular splintery fragments; much of it is cherty.

The upper member consists of very massive white or light-colored limestones showing no bedding planes, and in the Helena region they are commonly altered to white marble. The total thickness of the Madison is 2,600 feet.

Quadrant quartzite.—The Quadrant quartzite consists, as its name implies, chiefly of quartzite with sandstones and some interbedded white limestone. Throughout the area the rocks are much altered by contact metamorphism and their distinctive characters obliterated. The formation is named from Quadrant Mountain, in the Yellowstone Park, with which the rocks in this area are correlated. The formation composes the high hills adjoining the granite contact in the south part of the district. The thickness is estimated at from 190 to 500 feet. To the west, in the Philipsburg quadrangle, Calkins obtained from the Quadrant formation fossils which were pronounced by Girty to be of Pennsylvanian age. In other areas to the east in Montana, however, rocks referred to the Quadrant formation have yielded Mississippian fossils.

CRETACEOUS SYSTEM.

Rocks which are referred to the Cretaceous because of their stratigraphic position, and which possibly include some of Jurassic age, occur in the southern part of the area. They form a belt lying along the great granite mass which has invaded them and which in a number of places has broken the continuity of the belt. They consisted originally of sandstones and shales but have been subjected to intense contact metamorphism, so that now they consist of biotite hornfels and allied varieties of rocks.

TERTIARY SYSTEM.

Lake beds.—The Tertiary lake beds cover a far greater area than any other formation within the Helena district. The rocks vary in character from point to point according to the composition of the

underlying formation. In general they consist of well-bedded sands, gravels, and conglomerates composed of the underlying country rock, together with a large amount of rhyolite. In the center of Prickly Pear Valley, where the rocks have been penetrated by boring, several sheets of rhyolite have been found. In the hills to the east the beds are well exposed, and the indurated tuffs forming a part of the series are quarried in the vicinity of Lenox. As a rule, however, the rocks crumble on weathering, and good exposures are rare. These lake beds undoubtedly underlie the entire Prickly Pear Valley, but have been covered by detritus washed from the surrounding slopes and the alluvium brought in by the streams, so that although a thickness of over 1,200 feet is known from the bore holes put down in seeking artesian waters, the bottom of the formation has not yet been found. The rocks are nearly everywhere distinctly bedded, but as a rule they show little persistence in character. The pebbles are normally rounded but in part subangular, and as the material is mostly of local origin the color and composition vary from point to point. The beds are regarded as of Miocene or Pliocene age.

Hot spring deposits.—The hot spring deposits shown on the map (Pl. VII, p. 86) consist mainly of large masses of chalcedony.

Auriferous gravels.—The auriferous gravels of the Helena district are regarded as of Pliocene age, as the remains of the mammoth and other vertebrates believed to be of that age have been found in the vicinity of Helena and of Montana City. The gravels are composed of the harder, more resistant material from the drainage basins of the streams and naturally vary at different points. In the Montana City area there is a large proportion of andesite brought down from the headwaters of Prickly Pear Creek, together with much vein quartz and granite. In the Last Chance placer gravels, which underlie the city of Helena, the material has been derived from the various tributary gulches draining the granite contact and therefore consists of pebbles, cobbles, and well-bedded sands, composed largely of quartz monzonite, with varying proportions of limestone. Invariably the gravels are auriferous when the streams drain the contact region, and the source of the gold is to be found in the veins which follow the granite contact.

QUATERNARY SYSTEM.

The Quaternary deposits of the district consist of alluvial silts and gravels and are developed most extensively in the great plain north of the city of Helena.

IGNEOUS ROCKS.

Distribution and character.—Igneous rocks cover about one-fourth of the area of the district, forming high mountains to the south and the isolated peaks known as the Scratch Gravel Hills, as well as numerous lesser elevations. The oldest rocks occur only as intruded

sheets or sills in the Cambrian sediments and have been folded with them. They are of unknown age but are certainly pre-Tertiary. The most abundant rock is granitic in character and forms part of the Boulder batholith. The Miocene rocks occur as intrusive dikes and masses of rhyolite and as lava flows and tuff beds of the same rock. They also enter into the composition of the lake beds.

Basic dikes and sheets.—The basic dikes and sheets shown on Plate VII consist mainly of dark-greenish to steely-gray rocks of dense texture and commonly marked by rusty spots or the holes resulting from the alteration of augite and olivine crystals. Sometimes fresh augite is recognizable in the specimens. The commonest rock may be called a greenstone of diabasic character. It occurs intrusive in the Wolsey shale on the west side of Mount Helena and at the same horizon about a mile south of Lenox. Another dike of this material cuts the Flathead quartzite in the northwest portion of the city.

An augite porphyry, a tough and dense green rock containing white porphyritic crystals of plagioclase, occurs as a sheet 40 feet thick intrusive in a belt of black shale in the upper part of the Cambrian. This rock is exposed on the slopes east of Oro Fino Gulch, a short distance above the city, and it follows this shaly belt for a distance of several miles, outcropping at intervals.

A hornblende porphyry, a dark-green, fine-grained rock carrying stellate clusters of hornblende, occurs intrusive in the Helena limestone east of the Broadwater hotel. It forms a sheet 6 feet thick and outcrops for several hundred yards.

Acidic sheets.—A porphyry that contains altered feldspar phenocrysts but that is too thoroughly decomposed for specific identification occurs as a persistent sheet from 10 to 20 feet thick intrusive in the Wolsey shale close to the Flathead quartzite. It is exposed on the northeast side of Mount Helena and is traceable for several miles westward. A second sheet of similar nature occurs 30 to 40 feet higher in the shale.

Meta-andesite.—This name is applied to andesites which have undergone distinct alteration but whose original structure and composition are still recognizable. Patches of these rocks occur east of Montana City and at one or two other places in the Helena district. They are mostly fragmental in origin, being old volcanic tuffs and breccias baked and altered by contact metamorphism. A few intrusives are doubtfully referred to this type. They are older than the granitic rocks and in the region south of Helena form the cover to the granite. Fragments torn off by the granite intrusion occur in places in the later rock near its contact with the andesite.

Granitic rocks.—The coarse-grained rocks composed of feldspar and quartz, with lesser amounts of mica and hornblende, are conveniently called granite, as it is not usually possible to determine the species of feldspar in the field. A more precise definition, based on

a study of thin sections of the rock under the microscope, enables us to classify the material more exactly. In the granitic region extending southward from Helena to Butte the prevailing form of rock is a coarse-grained quartz monzonite, called the Butte quartz monzonite, which under the new quantitative system of classification is designated amiatose. A rock corresponding to this is seen in the Scratch Gravel Hills, at the south end, and also occurs in a small area near Holmes Gulch. The greater part of the granite of the Helena district is, however, a finer grained rock of slightly more basic composition.

Rhyolites.—The rhyolites are all of Miocene age and occur as intrusives, extrusives, and fragmentary rocks.

The rhyolite breccia covers a considerable area in the southeast part of the district. It is a mass that varies in character from place to place but is composed essentially of both rounded and angular fragments of rhyolite, lying without stratification and at all angles in a fine-grained stony matrix which is speckled with minute flakes of biotite and carries a few fragments of feldspar and quartz. The rock is generally light colored, varying from pale red and purple to buff color and white. Much of the fragmentary material composing the rock is a white, porous, pumice-like rhyolite. A good exposure is found in the quarry on Holmes Gulch $1\frac{1}{2}$ miles west of Montana City. At this place the breccia is a light, porous, somewhat friable rock, made up mainly of white rhyolite pumice, with small rounded pebbles of granite, jasper, and other rocks. It is regarded as a mud flow composed essentially of volcanic dust and ejectamenta which fell on the granitic slopes and was washed down to fill the hollows of the lower ground.

The rhyolite flows are readily distinguished from the intrusive rocks by their porosity and flow structure and as readily from the breccias by their compact nature. The rocks are prevailingly reddish to purple colored and contain phenocrysts of quartz, biotite, and in some specimens feldspar in a dense lithoidal groundmass. The chief exposures of this rock are in the vicinity of Montana City, one flow forming the cap to the highest hill in the region. The rock on this summit has a platy parting with a dip of 45° and forms extensive areas of slide rock on the west side of the hill but none on the east. It is evident that it was a lava flow covering a surface which has been much tilted since the consolidation of the lava.

Rhyolite intrusives are exposed in the vicinity of Lenox, where a patch one-fourth of a mile across and three-fourths of a mile long is intrusive in the Algonkian slates and has broken up and thrown over the Flathead quartzite. The rock is a normal rhyolite porphyry, showing phenocrysts of biotite, feldspar, and quartz in a stony groundmass.¹

¹ The present investigation shows that the rock is more accurately termed a dacite, and it is therefore so designated on Plate VII.

STRUCTURE.

The Helena district lies on the south side of a great dome-shaped uplift some 25 miles in diameter, whose center lies north of the Scratch Gravel Hills. This dome extends from the mountain ridge west of Marysville eastward to York, on the west side of the Big Belt Mountains. The city of Helena and the mountains south of it lie on the south side of the dome. Although the general structure is that of a simple anticline, the dome is not perfectly regular but shows secondary crumpling. Within the Helena district the dome shape is well shown. Subsequent to the folding which formed this great dome the granitic rocks broke through and faulted the south flank of this anticline.

Broadly considered, Prickly Pear Valley is a basin deeply eroded in the dome-shaped uplift noted above, an arch whose summit has been worn away and cut down into the soft shales of the Belt series that form its nucleus, so that the sheets of white limestone and other rocks that once covered it are now only seen on Mount Helena and the hills south of the city, in the Spokane Hills to the east, and the flanks of the Belt Mountains north of the district. This broad arch involved the entire sedimentary series of the region from Algonkian to Cretaceous. The simplicity of structure has been, however, modified by the granite intrusion and faulting.

The granite area in the southern part of the district (see Pl. VII), which forms a rugged mountainous tract, mostly unfit for agriculture and largely denuded of valuable timber, is the extreme northern part of a granite area extending 75 miles southward, a great mass of intrusive igneous rock designated the Boulder batholith. A part of this batholith extends northward under the sedimentary rocks, and, as already stated, the latter are highly altered and commonly crystalline, as a result of the heat and vapor given off by this once molten material. The upper contact between the granite mass and the bedded rocks is uneven, and arms and offshoots of the former rock extend upward. Some of these, bared by erosion, are seen as dikes and bosses, as, for example, the granite area near the Broadwater Hot Springs, that north of Helena, and a smaller area east of the city.

In the adjustment of the rocks following the violent intrusion of this great body of granitic rock, with its initial uplifting force and subsequent settling as cooling progressed, faulting occurred and the irregularly triangular blocks of the limestone series and their accompanying rocks were dislocated. These faults are not of very great magnitude. To the east, however, the bedded rocks were not clearly cut off, but broken into small blocks by the force of the intrusion, and a very complicated mosaic of sediments and igneous rock is shown on the map.

FAULTS.

The Helena area has a number of faults, which cross the stratified rocks at approximately right angles to their strike and which may be regarded as radial faults of the great anticline. Owing to the fact that the faults are marked by more or less crushed matter, which is easily eroded, they are followed by the stream gulches.

The West Side Reservoir fault shows an upthrow on the east with a horizontal offset of 500 feet and 290 feet vertical. This fault is indistinguishable where it passes through the massive beds of the Madison limestone, and in the Algonkian rocks the exposures are too few to determine it correctly. There are two small subsidiary parallel faults near-by, at the north base of Mount Helena. These faults have offshoots of 60 and 40 feet respectively, corresponding to 30 and 20 feet vertical, and have a downthrow on the east. On Montana Avenue, the north-south street separating sections 19 and 20, and 29 and 30, where the Flathead quartzite crosses, there are two small faults; one has a throw of 30 feet and the other, 100 yards farther east, has a throw of 15 feet.

A long northeast fault passing through Lenox splits at the north end into two faults 300 feet apart. The upthrow is on the west, and the fault displacements are 110 feet and 230 feet.

One-half mile farther east occurs the Mount Ascension fault. This is a big fault, having an offset of 850 feet (as the strata dips 40° this corresponds to 765 feet vertical). A half mile farther east is another fault of like magnitude. The wedge between these faults has sunk at least 765 feet, forming a trough or "graben."

These faults have been actually observed and measured, but it is probable that there are many faults of small displacement which have not been recognized, for the great block of altered sediments that rested on the granite while it was cooling must have suffered considerable contraction, with consequent fracturing and readjustment.

Strike faults due to slipping of the beds on one another probably accompanied the uplifting of the sediments. One was recognized southeast of Lena, where the Meagher limestone rests against Pilgrim limestone, the intervening shale being cut out.

In general the faults just noted can not be recognized in the relief of the region. A gulch marks the line of the Lenox fault (northeast-southwest) toward Unionville. The north-south fault on the east side of the depressed triangular block already noted seems to break into smaller faults and is strongly marked in the landscape. Several mine and quarry openings disclose its nature. The fault walls are smooth or polished and show well-marked striae. Between these vertical walls, which vary from 5 to 40 feet apart, the fissure is filled by friction breccia, ground up wall rock, showing angular and partly rounded rock fragments in a clayey matrix.¹

¹ Up to this point the text follows the manuscript of Mr. Weed.

ORE DEPOSITS OF HELENA DISTRICT.

LOCATION.

The ore deposits of the Helena district, using this term in its broad sense, are mainly located south of Helena along the heads of Oro Fino, Grizzly, and Nelson Gulches. Geologically they are situated mainly along the contact of the granite with the invaded sedimentary rocks—hornfels, quartzite, and limestone.

Opportunities for examination of the ore deposits were unfavorable during 1911. The properties were idle and most were inaccessible. The systematic position of certain of the deposits has already been pointed out—the Big Indian on page 51 and the Spring Hill on page 44—so that repetition is unnecessary here.

DESCRIPTIONS OF MINES.

WHITLATCH-UNION MINE.

The Whitlatch-Union lode, discovered by James W. Whitlatch in September, 1864, is the oldest quartz discovery in the region. The lode was rapidly developed by several different mining companies, each of which owned but a short length, the longest piece being the 500 feet held by the Whitlatch-Union Mining Co. By 1872 the mine had produced \$3,500,000, when it was shut down because of litigation. It has been operated intermittently since that time and is stated to have yielded to date \$6,000,000 in gold.

The mine was originally opened by a number of inclines, but with the exception of the Owyhee and McIntyre they are all caved near the surface. Later a vertical shaft was put down to a depth of 500 feet. During 1911 some of the upper levels were accessible through the Owyhee incline, from which in recent years lessees have been getting out small shipments of ore.

The lode is situated 4 miles south of Helena on the summit of the low divide between Grizzly and Oro Fino gulches. It lies in the granite just south of the contact with the Quadrant quartzite. There occur scattered in the granite near the contact some huge blocks of highly metamorphosed sedimentary rocks, probably belonging to the Cretaceous formation shown on Weed's map.

The general course of the vein is N. 84° W.; the dip averages 45° N., but is subject to remarkable and abrupt changes, ranging from nearly horizontal to vertical. In width the vein ranged from a thin seam up to 15 feet, averaging about 4 feet. The ore taken out in early days averaged from \$20 to \$25 a ton in gold.¹

As seen in the Owyhee incline the Whitlatch-Union vein is partly inclosed in hornfels and partly in granite. Abrupt changes in dip accompany the passage of the vein from the one rock to the other.

¹Statistics of mines and mining in the States and Territories west of the Rocky Mountains, 1889, p. 147.

A specimen taken from the footwall of the vein in the end of a drift driven west from the Owyhee incline is a dark heavy rock showing numerous small lustrous black flakes of biotite. When examined microscopically it is found to consist of a confused intergrowth of brown-green amphibole, biotite, and andesine, with accessory quartz. It is evidently a thermally metamorphosed rock, but further than this its origin is not apparent. It is possibly a recrystallized igneous rock.

The locality from which this rock was taken is in the newest workings of the mine. The vein here is narrow, averaging 4 inches, and dips at a low angle to the north. The ore consists of pyrite and some quartz and is slightly oxidized. A small shipment running \$70 a ton in gold was taken out; unmixed with waste the ore runs \$130 a ton.

BIG INDIAN MINE.

The Big Indian mine is situated 4 miles south of Helena. The two main claims, the Alabama and the Gold Hill, were located in 1875. The ore was taken out from a large quarry, and a 10-stamp mill was operated at a profit for a number of years. During the operation of this mill \$110,000 was produced, the ore averaging \$5 a ton in gold. According to James Winscott, the original locator of the property, some clean-ups ran 985 fine. Later the property was taken over by a corporation and a 60-stamp mill was erected and put in commission in 1902. This mill was operated by electric power from the Missouri River Power Co.'s plant at Canyon Ferry on Missouri River, and it was estimated that the ore could be mined and milled at a cost of 60 cents a ton. During 1903 and 1904 the Big Indian mine was the leading gold producer in Jefferson County, but soon afterwards it was shut down and has remained idle since that time.

The mine is situated half a mile south of the main contact of the granite with the sedimentary rocks on the north. The country rock is a gray medium-grained quartz monzonite. Under the last management the mine was worked by the glory-hole method, the glory hole being at the level of the top of the mill. The pit is several hundred feet in length and breadth and 50 to 75 feet deep. Near the surface the rock is soft and incoherent and crumbles easily, but toward the bottom of the pit it apparently grows hard. Near the bottom the granite is traversed by a close-spaced system of vertical jointing, along which considerable tourmalinization has taken place. About as much tourmaline was developed in the granite as the biotite and hornblende originally present. In addition to the tourmalinization there was a slight introduction of pyrite. Noteworthy is the fact that there are no quartz veinlets anywhere in the ore body.

The granite is cut by a few aplite dikes and also by some dark-colored diorite porphyry dikes. The tourmalinization ensued after the intrusion of the aplite dikes and probably after the intrusion of the porphyry dikes, which are somewhat pyritized.

SPRING HILL MINE.

The Spring Hill mine is situated 4 miles northwest of Helena in Grizzly Gulch. It is developed mainly by an adit tunnel and by levels below this tunnel. A 3,000-foot crosscut was driven to connect with the 500-foot level of the Whitlatch-Union mine in order to give the ore of the Spring Hill mine an easy outlet to the mill at Unionville.

The general country rock is the Madison limestone, which strikes N. 5° E. and dips 67° E., as shown on the surface near the large open cut. The ore deposit is located near the contact of a dark fine-grained gray granitoid, in which biotite is the most prominently recognizable constituent. As determined microscopically this rock is a diorite composed essentially of plagioclase, hornblende, and biotite, with subordinate interstitial quartz and orthoclase. The limestone is a white dense saccharoidal variety and shows selective metamorphism, for certain narrow bands from 2 to 3 inches wide show silication; that is, the development of pyroxene and garnet. At 50 feet from the contact some of these silicate bands fray out gradually into unaltered white limestone. Another open cut shows even more clearly that the development of silicate minerals is independent of the composition of the limestone, for metamorphic minerals are formed locally and abruptly across the bedding of thinly stratified limestone.

As seen on the main level the deposit consisted of a large body of contact-metamorphic ore which was stoped out in large high galleries, thick pillars of ore being left as supports. The ore minerals are pyrite and pyrrhotite; in places the pyrrhotite forms solid masses several feet in length and width. The sulphides are usually associated with a fine-grained aggregate of lime-silicate minerals that form an exceedingly hard and tough rock. They are also disseminated in grains and blebs through pure limestone. A notable feature of the deposit is the lack of oxidation exhibited, contrasting in this respect with other deposits in the region. The deposit is, as it were, doubly protected against the effects of enrichment, namely, by calcite¹ and by pyrrhotite,² both of which are effective precipitants for downward-moving solutions. The gold tenor is stated to run as high as \$30 a ton, but the average value makes this a low-grade ore.

DUTRO MINE.

The Old Dominion or Dutro mine, as it is known locally, is situated 7 miles west of Helena and 1 mile north of the Rimini road. During 1911 two men were employed here in getting out ore by means of a small gasoline hoist from an incline extending down 150 feet.

¹ Bard, D. C., *Econ. Geology*, vol. 5, 1910, pp. 59-61.

² Emmons, W. H., Public presentation before Geological Society of Washington, April, 1912.

The general country rock consists of a series of Paleozoic limestone and dolomite standing on edge and trending north and south. The mine is situated near the end of an intrusion of fine-grained diorite, whose longer axis, about one-fourth of a mile long, lies parallel to the strike of the inclosing rocks. The limestones are generally saccharoidal in texture and in places show abundant needles of tremolite. At the main working is a small boss of black fine-grained diorite about 150 feet in diameter.

The ore, occurring in irregular masses in the dolomite, consists of jasper and opal and usually contains much iron oxide. On account of the oxidized condition the original character of the ore is rather obscure. The prevailing ore is a jaspery quartz commonly showing specks of free gold. Locally it contains an iron-gray metallic mineral, which has been determined in the laboratory of the Geological Survey to be bismuth sulphide. The oxidation of this mineral seems to be the cause of the chrome-yellow color apparent in some of the ore. Under the microscope the ore is seen to consist of microcrystalline and cryptocrystalline silica, which forms a replacement of the dolomite. In addition to the minerals already noted, some cassiterite was detected. This is the only occurrence of cassiterite in its bedrock source yet discovered here, although it has been known to occur in the placer deposits of the region; the quantity is very small and the mineral could not be detected in hand specimens of the ore.

The ore is shipped to the East Helena smelter and is reported to average \$75 a ton in gold.

CLANCY DISTRICT.

Clancy is a small town in Prickly Pear Valley, 14 miles southeast of Helena. It was settled in 1865 and was formerly a thriving mining center, but is now chiefly dependent on agriculture and on the railroad, being a division point on the Havre-Butte branch of the Great Northern Railway.

GEOLOGY.

The prevailing rock is the typical quartz monzonite of the Boulder batholith. The abundance of aplite in dikes and large masses is noteworthy; some of the larger masses attain an area of several square miles, but they were not separately mapped. Intrusions of pegmatite and granite porphyry also are common.

Of the younger rocks, rhyolites are present in considerable quantity in the area east and northeast of Clancy. They were erupted on a surface whose relief was much like that of the present topography. Those east of Clancy are light-colored porphyries and include flow-banded, lithophysal, and breccia varieties. They are true rhyolites, consisting essentially of phenocrysts of quartz and sanidine inclosed in a microcrystalline groundmass of quartz and sanidine. Most of them

are devoid of dark minerals, but some contain scattered hexagonal plates of biotite. The rhyolite forming the butte at the mouth of Clark Gulch, north of Clancy, is strongly flow-banded; in places the banding, as a result of movement in the following lava, is contorted and stands vertical. Locally the rhyolite is filled with lithophysæ or "stone roses." The walls or petals of the lithophysæ are extremely thin and delicate and weather out readily, so that such rhyolites yield honeycombed outcrops.

Some dikes of rhyolite cutting the quartz monzonite occur locally; noteworthy among them are those paralleling the veins at the head of Warm Spring Creek. They commonly show margins several feet thick consisting of dark obsidian glass. West of Clancy, in the valley of Clancy Creek, a few dikes of dacite have been noted.

ORE DEPOSITS.

The mines in the vicinity of Clancy were founded on true silver ores; that is, ores valuable principally for their silver content. A considerable number of such mines were grouped in Lump Gulch, a few miles northwest of Clancy, and gave rise to a once flourishing mining camp called Lump Gulch City. All, however, are now idle. Of the mines of the Lump Gulch district, the Liverpool, credited with a production of over a million dollars, was the deepest and most productive. It attained a depth of 750 feet.

The veins were inclosed in quartz monzonite and carried rich argentiferous sulphides—galena, sphalerite, and tetrahedrite—in a chalcedonic quartz gangue. The only mine operating in 1911 on a vein of this type was the King Solomon mine, a description of which is given in some detail on pages 104–105. In its essentials this description doubtless applies to all the other mines. Dikes of dacite porphyry like that accompanying the King Solomon lode, however, were not noted at the Little Nell, Free Coinage, and Legal Tender mines.

The ore at the King Solomon mine is clearly of primary origin and is unaffected by enrichment; possibly, as suggested by the following description of the Legal Tender vein, the surface ores of the veins of this type were enriched to a certain extent by oxidation and the removal, by leaching, of some of the constituents.

A feature of the Clancy district is the abundance of iron-stained chalcedonic reefs, which form large, prominent outcrops. Some of these reefs carry a small amount of tetrahedrite. Their relation to the productive veins is not entirely clear; they are possibly somewhat younger or they may be merely the large barren equivalents.

The ore deposits at the head of Warm Spring Creek, a tributary entering Prickly Pear at Alhambra, 1 mile above Clancy, are of a different type than the foregoing and probably belong to the older mineralization. They are quartz veins, carrying mainly pyrite with

subordinate galena, sphalerite, and arsenopyrite, and yield a smelting ore running from \$15 to \$30 a ton, mainly in gold. They were inaccessible during 1911, although preparations were being made to reopen the Fleming, or Bell, mine, which has been the principal producer. These mines have recently been described in brief by R. W. Stone.¹

DESCRIPTIONS OF MINES.

KING SOLOMON MINE.

The King Solomon mine is situated on the north side of the valley of Clancy Creek, 2 miles west of Clancy. The property was located in 1889 but has been worked only intermittently since that time. The output has been \$100,000, mainly by lessees. In 1901 the mine was bought by Mr. I. S. Moreland, who organized the King Solomon Mining Co. During 1911 siliceous silver ore was being extracted and shipped to the smelter at Butte.

The mine is opened by an inclined shaft sunk on the lode to a depth of 300 feet. Development and exploitation is at present proceeding on the 300-foot level, west of the shaft.

The country rock at the mine is a coarse granite, the chemical and mineralogic features of which are described in detail on pages 56-58. Some dikes of fine-grained white aplite cut the granite but are of small importance. Of considerably more importance is a thick porphyry dike, which forms the hanging wall of the King Solomon lode. The dike trends slightly south of west and dips 60° to 70° S.; as shown by a crosscut on the 200-foot level it is 85 feet wide and the walls are rather wavy. In appearance the dike strongly resembles a granite porphyry, but familiarity with the rocks of the region suggests that it is allied to the highly porphyritic dacites so abundant at Wickes and elsewhere. It is an ash-gray porphyry, holding abundant crystals of feldspar and quartz, and numberless small brilliant black flakes of biotite, the phenocrysts forming half of the rock. Under the microscope the feldspar phenocrysts are found to be crystals of glassy andesine ($\text{Ab}_{50}\text{An}_{44}$) and are seen to be embedded in a groundmass of cryptocrystalline texture. The identity of the rock as a dacite is thus established. The ore body, being younger than the dike, is therefore of late Tertiary age, a fact immediately suggested by the prevalence of chalcedonic quartz in the gangue matter of the lode.

The lode consists of a wide shear zone, traversing mainly granite but in places aplite also. It trends parallel to the dacite dike, which forms, as it were, a hanging wall to the ore deposit, the course of the dike, as already pointed out, being somewhat wavy, but the lode pursues a straighter course than the dike and touches the footwall of

¹ Geologic relation of ore deposits in the Elkhorn Mountains, Mont.: Bull. U. S. Geol. Survey No. 470, 1911, pp. 87-88.

the dike at the crests of the waves only. At such points the dike is generally much sheared and altered. The granite adjoining the lode for a distance of at least 20 feet is softened and has been greatly altered through the action of the ore-forming solutions, as described in detail on pages 56-58.

The lode, or ore-bearing zone, measured normal to the dike, is 25 feet or more wide, but of this width the ore aggregates a few feet at most. The ore consists of narrow slabs of high-grade material trending parallel to the structure. In rich places along the lode the ore forms a series of imbricating slabs of nearly solid sulphides $1\frac{1}{2}$ to 3 inches thick, constituting short ore shoots aggregating from 1 to 2 feet in thickness. The metallic minerals are essentially galena, sphalerite, and tetrahedrite; pyrite is rare, but molybdenite has locally been found in some abundance. The sulphides are irregularly intergrown and are of contemporaneous and primary origin. Ore high in tetrahedrite is rich in silver. The sphalerite is mainly the resin-colored variety. The gangue of the ore-bearing veinlets is principally chalcedonic quartz. Some of the ore, however, is highly brecciated and angular fragments of chalcedony and of sulphide aggregates have been recemented by fine-grained curved siderite.

The ore is carefully sorted, and a product high in silver is obtained, carrying between 100 and 200 ounces a ton.

On the 200-foot level, east, the dacite dike was crosscut and much gouge and shattered granite, in places 4 feet wide, was found on the hanging wall of the dike. Streaks of rich ore were encountered here, and a ribbon of ore $1\frac{1}{2}$ to 8 inches wide, consisting essentially of resinous sphalerite intergrown with tetrahedrite in a quartz gangue, was found; this constituted 400-ounce rock.

LITTLE NELL MINE.

The Little Nell was the only mine of the Lump Gulch mines at which there was some activity during 1911. The main operations consisted in reworking the old dumps, but some underground work was also done. The mine was partly unwatered and a tunnel was run westward on the 150-foot level in the expectancy of reaching an ore shoot.

The old workings attained an extreme depth of 500 feet and smelter returns show a production of \$400,000. The geologic and mineralogic features are similar to those of the King Solomon lode, namely, an argentiferous galena-sphalerite ore in a chalcedonic quartz gangue. As a rule, ore high in zinc is also high in silver.

YELLOWSTONE PROSPECT.

The Yellowstone group, comprising 10 or 11 claims, is situated on a small stream tributary to Clancy Creek, 5 miles west of Clancy. A 90-foot shaft had been sunk on the prospect by former owners and had

been abandoned, but the property was relocated in 1908 by the present owners. A drift tunnel, which is now 200 feet long, was commenced by the new owners 150 feet below the collar of the shaft.

The country rock is quartz monzonite, carrying large porphyritic orthoclase crystals and abundant biotite in hexagonal plates. The lode is considered to be 25 feet wide; the footwall is not well defined, but toward the hanging wall there are a number of good walls which show considerable gouge and horizontal corrugation. The 25-foot ore-bearing zone contains a number of thin and widely spaced veinlets; the ore minerals are principally chalcopyrite and galena, with minor amounts of sphalerite and pyrite. The gangue is mainly quartz, grading in places into chalcedony. Azurite in small quantity and a little malachite are found on the surface. The lode, which strikes east and west and dips 65° S., apparently cuts across a dacite dike 90 feet wide and trending nearly north and south.

KENNEDY OR JACKSON CREEK MINE.

The Kennedy mine is one of the old mines of the district that has been recently reopened. The former workings are said to have attained a depth of 250 feet. The ore consisted of rich silver sulphides, which, in 1872, were hand sorted and hauled to Fort Benton by ox teams and shipped to Swansea, Wales. The old workings are no longer accessible. An incline of 69° has recently been sunk to a depth of 115 feet and a crosscut back to the ledge on the 100-foot level was commenced.

The country rock is a coarse granite, consisting of orthoclase, plagioclase, quartz, and biotite. At the surface this has been disintegrated to a sand through which project a few hard fresh aplite dikes. Three parallel ledges occur on the property, trending east and west. One that is being prospected by pits shows an overburden of disintegrated granite 10 feet thick. In places the ledge is represented by oxidized sheared granite.

LEGAL TENDER MINE.

The Legal Tender mine is situated a short distance east of Clancy. According to Raymond,¹ writing in 1873:

This lode is a true fissure vein, cutting through granite, and is considered the richest and best developed silver property in the Territory. The ore and vein matter varies in thickness from 1 to 3 feet, increasing gradually in width as depth is obtained. A portion of the ore in the vein is a very rich argentiferous galena, carrying a larger or smaller quantity of dark-brown zinc blende, sulphurets, and carbonates of lead, oxide of manganese, iron, copper, and antimony, with streaks in which native wire, flake, sheet, and ruby silver occur abundantly. The heaviest galena ores contain black and gray sulphurets of silver, and yield from \$2,000 to \$4,000 per ton. A fine blue quartzose ore predominates, in which occurs very frequently native and ruby silver. A

¹Statistics of mines and mining in the States and Territories west of the Rocky Mountains, 1873, p. 230.

small portion of these ores can be successfully reduced by the smelting process, as has been demonstrated in the works at Helena and Jefferson City; but the larger portion of the ore from this mine can be most profitably reduced by the milling (roasting, chloridising, and amalgamating) process. The lode was first discovered by Joseph Fuлтs in 1866, but no work of development was accomplished until 1872, under the management of its present owners, who came into possession in the winter of 1871-72. Up to May 1, 1872, a shaft was sunk only to the depth of 60 feet, which, however, demonstrated the existence of a true vein and a body of very rich ore. Since that time work has been prosecuted with vigor, and large and commodious whim, shaft, and ore houses have been erected, with company office, assay office, and other necessary buildings.

The mine is developed to the depth of 160 feet, showing an increasing width of vein with depth. At the depth of 80 feet levels were run 140 feet east and 90 feet west, and at the depth of 160 feet the east level is out 130 feet. Some stoping has been done east of the main shaft. An air shaft 60 feet west of main shaft extends down to the 80-foot level.

From the commencement of work by the present owners up to January 1, 1873, the mine has produced 7 tons of ore yielding \$6,090 coin value, or at the rate of \$870 per ton; also 130 tons of ore yielding \$54,000 coin value, or at the rate of \$417.78½ per ton; and 240 tons yielding \$31,607 coin value, in lots, at rates varying from \$128.42 to \$202.49 per ton. About 175 tons of second-class ore are now on hand.

* * * * *

The first-class ores have mostly been shipped out of the Territory in wagons to Corinne, thence to San Francisco and Europe.

The mine has long been idle and dismantled. The preceding description has been thus fully quoted because the facts therein presented, taken together with the present condition of the mine, give an accurate picture of what has happened to so many other mines throughout this same region.

From what can now be seen on the surface, the vein ranged from 4 to 6 feet in width, trended N. 80° E., and dipped vertically. It belonged to the same type of ore body as the King Solomon. The fine blue quartzose ore of Raymond's report is the fine-grained flinty or chalcedonic quartz of this report. Ninety feet south of the Legal Tender shaft are huge iron-stained outcrops of one of the chalcedonic reefs so common in this part of the district. The Legal Tender vein is either cut off by this reef or converges with it at a narrow angle approximately 200 feet west of the shaft.

WICKES DISTRICT.

LOCATION AND HISTORY.

The Wickes district has been the largest producer of silver-lead ore in Jefferson County. Within the district as designated in this report, are included the towns of Wickes, Corbin, and Jefferson, and the deserted mining camps of Gregory and Comet. Jefferson was settled in 1864 and Wickes in 1877. Corbin is considerably more recent.

Wickes is situated 20 miles south of Helena on the Great Northern Railway. Formerly it was served also by a branch of the Northern

Pacific Railway, extending from Helena, but this line was abandoned about 1900. The large smelting plant of the Helena Mining & Reduction Co. was situated here and was operated until 1893, when it was shut down. It has never been started again and is now a wreck. This blow, together with the cessation of mining at many of the properties in the vicinity, destroyed the prosperity of Wickes. Corbin, situated 2 miles below Wickes, has in recent years enjoyed a copper boom on account of the large bodies of ore believed to exist there, but since the panic of 1907 the boom has largely collapsed.

Although the district contains an array of mines noteworthy for their output—the yield of the Alta, Comet, Gregory, and Minah mines aggregating over \$50,000,000—only one property was shipping ore in 1911. This was the Blue Bird mine, which produces a copper-silver ore. Extensive development work, however, was in progress at the properties of the Boston & Corbin Gold & Silver Mining Co., Corbin Copper Co., and Corbin Metals Mining Co.

GEOLOGY.

The oldest rocks in the Wickes district belong to the series of andesites and latites. They form the largest remnant of the cover under which the granite of the Boulder batholith cooled. Massive lavas, breccias, and an unusual proportion of fine-grained tuff and argillaceous rocks are found. In places the andesites, or more probably latites, display conspicuous flow streaking, as near the summit outcrops of the Alta lode and along the road from Wickes to Gregory. The prevalence of banded tuffs allows the dip and strike to be determined more readily than is generally possible in the andesite-latite series. Measurements show that, although flat dips are of general occurrence, steep dips up to 45° are common. These dips are steeper than those obtaining along the margins of the batholith; furthermore, the strike of the beds is inconstant in direction. This structural complexity suggests a possibility that the roof remnant has suffered partial foundering and collapse during the intrusion of the quartz monzonite.

The granitic rock of the Wickes area is the normal quartz monzonite of the Boulder batholith. It is intruded, however, by unusually large masses of aplite, the largest of which is shown on the geologic map (Pl. I, p. 20). Another large area, probably approaching in size that east of Corbin and Wickes, lies west and southwest of Jefferson. Dikes of aplite also are common in the quartz monzonite and in the andesites.

West of Wickes is a considerable area of dacites that form a series of prominent white and light-gray porphyries. These rocks rest on the eroded surface of the andesites and granite and are therefore considerably younger. Dikes of dacite pierce the older rocks; some

of these that carry few or no quartz phenocrysts are, strictly speaking, biotite andesites and are not easily distinguishable from diorite porphyries.

DESCRIPTIONS OF MINES.

ALTA MINE.

The Alta mine, whose output of \$32,000,000 is by far the largest of the mines in the region, is situated on Alta Mountain, 2 miles southwest of Corbin. It was developed by a series of tunnels, the lowest of which is known as the 800-foot tunnel, although it is considerably less than 800 feet vertically below the summit of Alta Mountain. The property, together with many others in the vicinity of Wickes, was acquired in 1883 by the Helena Mining & Reduction Co. A smelter, which was for some years the largest reduction plant in Montana, was built at Wickes, and regular mining operations continued until 1893. Since then an intermittent production has been maintained by lessees. In 1909, however, the property was taken over by the Boston & Alta Mining Co. and a shaft, situated near the mouth of tunnel No. 8, was sunk to a depth of 600 feet. Drifting was commenced to intercept the vein below the old levels, but operations were suspended in August, 1910. Lessees were engaged during 1911 in extracting carbonate ore from shallow surface workings and grass-root tunnels near the summit of Alta Mountain.

The production of the mine previous to 1893 is stated to have been 1,250,000 tons of ore, aggregating \$32,000,000, mainly in lead and silver, and up to that time only the highest grade ore was shipped.¹

The prevailing rock in the vicinity of the Alta mine is a latitic andesite. The rock at the summit of the mountain shows a pronounced streaky and flow-banded structure. The intrusive granite occurs several hundred yards east of tunnel No. 8; on the wagon road below the mine a dike of coarse aplite and two dikes of dacite 50 or 100 feet wide are exposed, penetrating the andesites.

The underground workings being inaccessible, only surface observations could be made. These show that the ore body, trending slightly south of west, was inclosed in the andesites and that the ore minerals consisted of galena, sphalerite, and pyrite. The introduction of the ore, as shown by material on the dumps at 6,100 feet altitude, was accompanied by intense tourmalinization, so that radial aggregates of black tourmaline are common in the altered andesite. In places the andesite was fractured and netted with quartz tourmaline veinlets and impregnated with pyrite. Such rock examined microscopically proves to be composed of quartz and sericite in nearly equal abundance, tourmaline, and pyrite.

¹ Mineral Resources U. S. for 1909, U. S. Geol. Survey, 1910, p. 374.

The output of \$32,000,000 of lead-silver ore entitles the Alta lode to rank among the world's most notable deposits of lead-silver ore occurring in noncalcareous rocks. Further, this great yield would seem to give it foremost place in the class of tourmalinic ore deposits.

BERTHA MINE.

The Bertha mine, the property of the Boston & Corbin Copper & Silver Mining Co., is situated 1 mile west of Corbin. The company was organized in 1907 and the main work done on the property has been accomplished since that time. A 2-compartment shaft, operated by a balanced electric hoist, was sunk to a depth of 900 feet, which was the bottom level of the mine at the time of visit. This level, however, is called the 1,200-foot level, owing to the fact that the discovery croppings are situated 300 feet above the collar of the shaft. It is planned to erect a 300-ton concentrator on the property.

The country rock is a coarse gray granite or quartz monzonite. The vein trends northeast-southwest and dips steeply northwest, commonly in excess of 80° . Drifts have been run along the vein southwest from the shaft on various levels and a considerable tonnage of ore has been blocked out. The vein ranges in thickness from a few inches to a maximum of 10 feet and on the 700-foot level averages about 4 feet; on the 900 and 1,200 foot levels it is somewhat narrower. The vein on the 700-foot level has a well-marked ribbon structure, where undisturbed, but much postmineral movement has taken place and the quartz is brecciated along the footwall. This postmineral movement was mainly horizontal, as shown by corrugations on the walls, and took place chiefly along the footwall, which is overlain by a layer of gouge in places $1\frac{1}{2}$ feet thick. Locally this gouge is somewhat stained with iron oxide. The granite adjoining the vein on the 700-foot level shows white chalky feldspars, which give it a porphyritic appearance; it slacks and crumbles readily. In this phase the biotite plates have remained unattached and lustrous; in other phases both feldspar and biotite are sericitized and the rock is more highly pyritized.

The ore is a coarse white quartz, carrying chalcopyrite and pyrite, and is stated to average from 2 to 3 per cent copper, with small values in silver and gold. Some of the ore carries small amounts of a lead-gray mineral, locally known as gray copper, but which, on qualitative chemical analysis, proves to be a sulphide of lead and bismuth answering to the description of cosalite. It would probably be a matter of some metallurgical interest to determine whether this mineral carries any silver, as it will undoubtedly slime during concentration. Some bornite occurs in small amount on the 700-foot level, but is not found above or below this level. It may represent

local enrichment, but this is doubtful. Other than the occurrence of this bornite, there is no evidence of sulphide enrichment, and the bulk of the ore is clearly of primary origin.

According to a recent report,¹ a carload shipment of average ore for testing purposes sampled 3.6 per cent copper, 7.1 ounces of silver, and 20 cents in gold to the ton.

BLIZZARD MINE.

The Blizzard mine is situated 3 miles west of Wickes. It was operated by a company from 1888 to 1896 and by lessees from 1899 to 1906. In 1911 three men were engaged in exploring the property with a view to opening it up again. The old workings produced about \$150,000, smelter returns showing that the ore carried from 0.1 to 0.8 ounce of gold and 10 to 60 ounces of silver to the ton and 6 to 20 per cent of lead. There are two veins on the property, and of these only the northern vein carries ore. The northern vein occurs in a shear zone in andesite and ranges in thickness from a few inches to 6 feet. The joint planes in the andesite near the vein are at many places heavily pyritized; rarely slight tourmalinization occurs along the joints in the andesite, but occurs nowhere in connection with the ore. The ore consists principally of pyrite and arsenopyrite, in places with small bands and patches of galena, sphalerite, and blende, rarely chalcopyrite. Practically no quartz is present.

The smelter returns show that this ore carries 0.3 ounce of gold and 14 ounces of silver to the ton, 8.5 per cent of lead, and 1.3 per cent of copper. The southern vein, which is said to fault the northern vein, occupies a fault plane in the andesite and dips 45° N., except at the east end near the fault, where it dips 85°. The filling of this vein consists of pyrite, rhodochrosite, pyrolusite, calcite, and quartz.

BLUE BIRD MINE.

GENERAL FEATURES.

The Blue Bird mine is situated at an altitude of 7,000 feet, 4 miles west of Wickes. It is one of the old mines of the district, and the property, recently enlarged by the purchase of the adjoining Penn Yan claim on the west, was taken over in 1911 by a new company, which is proceeding to develop the mine systematically.

The authenticated production is \$175,000, but the amounts taken out by lessees from time to time are believed to bring the total up to \$250,000.

The main haulage way, whose portal is situated 400 feet below the highest point on the outcrop of the lode, consists of a crosscut tunnel 648 feet long bearing S. 45° W., and a tunnel following the trend of

¹ Eng. and Min. Jour. vol. 93, 1912, p. 668.

the lode for 1,600 feet in the general direction N. 80° W. The tunnel, which is of somewhat devious course, though considerably straightened by the present management, will eventually undercut the lode beneath a shoot of ore known to have been exploited in the summit workings. This shoot was 350 feet long and has been stoped out from the 120-foot level to the surface. The ore averaged 0.56 ounce in gold and 65 ounces in silver to the ton,¹ being considerably higher in precious metals than the ore now mined.

Geologically the Blue Bird mine is situated on the western margin of a large andesitic area that constitutes a remnant of the roof under which the quartz monzonite was intruded. It lies at the head of a long embayment of the quartz monzonite extending into the andesites, an embayment sufficiently pronounced to be apparent on the geologic map, even with the small scale employed. On account of this proximity to the intrusive contact, various granitic dikes, comprising quartz monzonite, aplite, and diorite porphyry, penetrate the general country rock at the mine. Contact-metamorphic alteration also has affected the rocks, especially those on the west end of the property.

The rocks at the Blue Bird mine consist principally of andesitic tuffs grading into hard shales. They are known locally as "slates,"² but none show slaty cleavage. Such local terms are apt to be misleading in a general report, so the term will not be used here; it need but be pointed out that the "slates" at the Blue Bird mine are in no respect similar to the rocks locally called "slates" at Marysville. A specimen taken 100 feet south of the lode line at the summit of the hill is a massive fine-grained greenish-gray rock of andesitic appearance. Under the microscope its tuffaceous character becomes apparent. It is seen to be composed of plagioclase fragments with numerous epidote aggregates and chlorite scales embedded in a cryptocrystalline matrix. Some of the coarser-grained rocks are clearly of pyroclastic origin, but the finer-grained rocks are less easily discriminable, and it is of course impossible to draw any hard and fast line between argillaceous tuffs and pure shales. Here, as elsewhere in the region, as shown under the systematic treatment of the geology (pp. 23-29), lava, tuff, and argillaceous rocks occur interstratified. Undoubted massive porphyritic andesite, possibly latitic like that on Alta Mountain, is found in the mine; it was specially noted in drift No. 812. The bedded andesitic tuffs, as shown in a cutting near the superintendent's house, strike north and south and dip 40° E.

Diorite porphyry forms extensive outcrops 800 feet north of the lode line, and similar rock has been encountered on the main haulage

¹ Winchell, H. V. and A. N., Notes on the Blue Bird mine: Econ. Geology, vol. 7, 1912, p. 287.

² They are so termed by H. V. and A. N. Winchell, op. cit., p. 292.

level of the mine. The relation of this rock to the surrounding rocks has not been determined, and it is not known whether the diorite porphyry preceded or followed the quartz monzonite intrusion. Diorite porphyry from crosscut No. 605, locally termed granite, is a highly porphyritic rock containing numerous plagioclase phenocrysts and hornblende inclosed in a microcrystalline matrix. Under the microscope the plagioclase phenocrysts are found to be labradorite near Ab_1An_1 and remarkably clear and well preserved, in view of the altered condition of the rest of the rock. The porphyritic hornblendes are largely changed to confused intergrowths of actinolite. The groundmass is composed essentially of a microgranitic aggregate of orthoclase and quartz, with accessory magnetite. Common secondary minerals are chlorite, epidote, and pyrite. The diorite porphyry mass in drift No. 605 shows various phases; where pyritized and sericitized it is light colored, and where mainly tourmalinized it is nearly black. Such kinds of alteration took place concurrently with the formation of the lode, and a small pocket of 2-ounce gold ore, consisting of columnar arsenopyrite embedded in a matrix of sphalerite and pyrite, was encountered in this altered diorite porphyry, which is therefore clearly older than the ore body.

Dacite is the youngest igneous rock at the mine. It forms a 50-foot dike lying in the footwall of the lode and dipping 70° S. The dike is apparently several thousand feet long, having been noted at the Penn Yan shaft on the west and at the Abe tunnel on the east. The dacite is a light-gray porphyry holding phenocrysts of quartz, plagioclase, and biotite in numerous small hexagonal plates. The characteristic features of this rock are sufficient to establish its identity with the extrusive dacites of the region, which are so well developed a few miles east of the mine. The dacite dike was therefore injected long after the main mineralization at the Blue Bird mine had taken place. Some brecciation of the footwall of the dike has occurred, followed by a slight introduction of pyrite, but this mineralization was of no economic importance.

THE ORE.

The ore occurs in shoots along a profoundly tourmalinized zone trending approximately east and west. On the 200-foot level of the Blue Bird shaft a crosscut into the hanging wall shows 40 feet of tourmalinic rock. This rock is of striking appearance and shows, contrasted against a light-colored matrix, a great number of radial groups of black columnar tourmaline, the largest several inches in diameter. Arborescent growths are common. Microscopically the rock is seen to be composed of tourmaline, quartz, sericite, pyrite, and apatite. The tourmaline ranges from broad columns of brown-green color to long colorless ultramicroscopic needles

traversing a succession of consecutively adjoining quartz grains. Apatite, although ranking as an accessory mineral only, was probably introduced with the tourmaline and pyrite. The rock as a whole has been so thoroughly recrystallized that its original character is no longer recognizable. The ore is found in rock of this kind. Along the lode some remarkably thorough postmineral brecciation and crushing has taken place, producing rounded fragments of ore embedded in a clayey matrix.

In the workings on the main haulage way and in the two levels below it, the features of the ore-bearing zone are somewhat different. A tourmalinic breccia occurs on both sides of a granitic dike, which is 10 to 15 feet thick and dips 70° S. In places this granitic dike is intensely shattered. The tourmalinic breccia is not continuously developed along the course of the dike. It is composed of angular fragments of various rocks cemented together by a black fine-grained aggregate of tourmaline and quartz. This cement is similar in composition and appearance to the "black quartz" at Rimini. Among the rock fragments inclosed in the breccia, granite is most easily recognizable, but many light-colored fragments of fine texture are present, which are probably the highly altered equivalents of the andesitic tuffs. The granite has undergone extreme metamorphism and now consists essentially of quartz, sericite (unusually well developed in fan-shaped groups), tourmaline, and cubical pyrite. Arsenopyrite is found locally.

Isolated bodies of ore-bearing tourmaliniferous rock are found parallel to the tourmalinic breccia. Along the strike, where the tourmalinization was feeble, the tourmaline rock is represented, as in drift No. 812, by a series of vertical stringers of tourmaline 1 inch wide, which consist of a succession of radial groups centered along a crack commonly lined with pyrite.

The ore shipped to the smelter during 1911 was composed principally of iron-black tetrahedrite and pyrite intergrown with perfect radial groups of tourmaline, commonly under half an inch in diameter. The pyrite has a tendency to occur as large irregular or distorted cubes. Sphalerite and galena are rare constituents. Under microscopic examination such ore shows tourmaline, quartz, pyrite, tetrahedrite, sphalerite, and galena. The thin delicate prisms of tourmaline pierce the various sulphides and all the minerals appear to be essentially contemporaneous.

The ore is stated to carry 10 to 25 ounces to the ton in silver, 3 to 5 per cent of copper, and small amounts of gold.

COMET MINE.

The Comet mine, the property of the Montana Consolidated Copper Co., lies 7 miles northwest of Boulder. It has been one of the largest producers in the region and is popularly credited with a produc-

tion of \$13,000,000. For some years no systematic work has been in progress; during 1911 four different parties of lessees were at work getting out ore above the tunnel levels.

The mine lies near the contact of the quartz monzonite and the andesite. On the summit of the ridge northeast of Comet the andesite, which is of massive porphyritic character, is tourmalinized, showing numerous well-developed radial groups of tourmaline. Farther northeast on this same ridge considerable coarse andesitic breccia is exposed and shows much tourmalinization accompanied by development of sericite. The country rock at the Comet mine itself is a fairly coarse grained quartz monzonite. A large pit over 100 feet long and 30 feet wide, on the summit of the hill east of the shaft, contains a few horses of quartz mixed with altered granite, which is intensely sericitized and shows a small development of tourmaline. This feature indicates that the Comet ore body belonged to the older tourmaline-bearing set of deposits. In confirmation of this is the fact that the ore body is cut by a dacite dike 35 feet wide; much rock from this dike can be seen on the mine dumps where, because of its striking appearance, it is quite conspicuous. It shows large quartz phenocrysts and altered feldspars embedded in a gray matrix commonly showing fluxion structure.

The old mine workings are generally inaccessible; the timbers are crushed and the tunnels caved. At one place the lessees are taking out ore from three parallel lenticular masses trending east and west and dipping nearly vertical. The ore is a solid mass of sulphides, more or less oxidized, and is usually accompanied by a vein of quartz against one or other of the walls. The granite is much shattered and slickensided and reduced to gouge. The ore is commonly kneaded into fragments embedded in vein matter. The ore minerals are essentially galena and sphalerite, with which are associated pyrite and chalcopyrite and rarely arsenopyrite.

CORBIN COPPER CO.'S PROPERTY.

The property of the Corbin Copper Co., comprising about 40 patented claims, is situated at the head of Clancy Creek, a few miles west of Corbin. A large amount of development work has been done here in recent years and a concentrator has been built on the property. At the present time most of the work is being done on the Dewey and Bonanza tunnels.

The country rock consists mainly of andesitic tuffs and interstratified argillaceous beds. The tunnels above the Dewey tunnel show a zone of shattered and leached rocks at least from 60 to 100 feet wide. Near the mouth of the Bonanza tunnel are large reef-like croppings of red-weathering tourmalinized andesite. The rock exposed in the Bonanza tunnel is generally soft and of granitic appearance. It is a gray medium-grained granitoid, in which biotite is the only mineral

certainly recognizable, and is evidently an intrusive dike in the andesites. Under the microscope it shows an aplitic texture and is seen to consist of plagioclase, orthoclase, micropegmatite, and biotite. In places in the tunnel this rock has been highly altered, so that it is now made up largely of tourmaline and forms exceedingly hard and resistant material. It is composed, as determined microscopically, of quartz, brown tourmaline, sericite, and pyrite, accompanied by accessory apatite and zircon. Locally masses of ore, composed of galena and chalcopyrite associated with pyrite and sphalerite, occur in the tourmalinic rock. At the time of the writer's visit a raise was being put through on a mass of ore of this kind from the Bonanza tunnel to the Dewey tunnel, 207 feet above.

The Rosalie tunnel, situated 2,000 feet southeast of the preceding tunnels, shows dense-grained argillaceous rocks lying horizontally or inclined at low angles to the south. A drift was run on a narrow vein more than 800 feet. The vein shows a remarkably fine and continuous hanging wall. It is faulted in places, the greatest displacement encountered being 35 feet. The ore was an oxidized pyritic ore, showing considerable tourmalinization. It was of good grade, but on account of the small quantity found work has been suspended on this vein.

In the Montana tunnels a mineralization of an entirely different character and origin from that of the Rosalie tunnel is exposed. It consists mainly of a pyritized conglomerate associated with dacitic tuff and massive dacite, showing flow banding. In the upper tunnel pyritization ceases against the massive dacite, which forms a sort of hanging wall. A winze to the lower tunnel, 35 feet below, shows that the rock is considerably impregnated with pyrite, perhaps to the extent of 3 or 4 per cent. Galena occurs rarely. The rock along the upper tunnel is said to average 8 ounces silver for a distance of 130 feet.

The tuffaceous rock is soft and incoherent in the tunnels but hardens on exposure to the atmosphere. The conglomerate carries well-rounded cobbles, the largest 12 inches long, some being dacite, some alaskite, but the most andesite. It holds irregular lenses of white material, probably tuff, abruptly delimited from the inclosing rock. In the lower tunnel the conglomerate is overlain by a flow of dacite dipping 20° N. At other places massive dacite abuts against the conglomerate along fault contacts.

CORBIN METALS MINING CO.'S PROPERTY.

The Corbin Metals Mining Co., whose property is situated about 2 miles southeast of Corbin, is developing the Silver King and other lodes. An incline has been sunk to a depth of 400 feet and considerable drifting and cross-cutting has been done. Five parallel

veins, inclosed in the granite country rock and trending N. 30°–45° E., have been crosscut. The veins are strong shear zones, ranging in thickness from a few inches to 8 feet. They are filled with crushed granite, which has been sheared into small irregular lenticles. Some of the veins are tight and dry, but others let in considerable water. As seen on the lowermost level the gangue material of the veins is somewhat altered by vein-forming solutions and slightly pyritized. There is no evidence of oxidation at this depth, nor that enrichment has taken place, and it is clear that the zone of primary sulphides has been encountered. The metallic minerals noted in material on the dump are pyrite, galena, subordinate sphalerite, and rarely molybdenite.

GREGORY MINE.

The Gregory lode was located in 1864 and is therefore one of the oldest properties in the region. The workings are now inaccessible, the surface plant destroyed, and the smelter is represented by only the stumps of the stacks. The production, according to popular report, was \$8,000,000 in lead and silver.

The mine lies near the contact of the andesite and a tongue of diorite intrusive from the main mass of quartz monzonite. The upper Miocene dacites, as shown on the geologic map (Pl. I), occur a few hundred feet south of the mine but are of later origin than the ore bodies. The dumps show mainly andesite, which is commonly pyritized and in places slightly tourmalinized. Diorite is present in smaller amounts and is as a rule pyritized and sericitized. The ore consists of galena, sphalerite, and pyrite. According to Mr. Lindgren, who was assayer at the mine in 1883, the ore worked at that time was extremely high in zinc, and ore carrying as much as 15 per cent zinc was smelted.

HORSESHOE PROSPECT.

The Horseshoe prospect lies 2 miles west of Corbin. Several hundred feet of tunnel have been drifted along an irregular intrusion contact of aplite and andesite. The aplite is highly tourmalinized, pyritized, and sericitized. The andesite also shows a similar set of alterations, but a further alteration has been superposed upon the earlier by the action of downward-moving sulphate solutions. Exposed surfaces in the tunnels are covered with needles of gypsum, and the andesite when broken open is found to be permeated with flat crystals of gypsum. In addition to the aplite and andesite, masses of dacite were encountered in the tunnels and complicate the geology. The contacts of the dacite with the other rocks are sheared, and this shearing is probably a measure of the amount of postmineral movement, as the dacite itself is unmineralized and shows neither the intense tourmalinization nor sericitization that the older rocks

The primary mineralization, in which apparently the principal metallic sulphide introduced was pyrite, therefore took place after the intrusion of the aplite and before the intrusion of the dacite. Pyrite has possibly been introduced after the dacite came into place, but in comparatively small amount.

MINAH MINE.

The Minah, one of the old and well-known mines in the Wickes district, is situated $1\frac{1}{2}$ miles northwest of Wickes. According to popular report the production has been \$2,000,000, but the property is now idle and the smelter dismantled. During 1901 the output aggregated 3,000 tons of shipping ore, which carried 20 ounces of silver and \$12 in gold to the ton.¹

The country rock is a highly porphyritic dacite, showing large phenocrysts of striated feldspar, numerous small quartzes, and small black flakes of biotite. The ore bodies, however, seem to have been not in the dacite, but in the underlying andesite. The mine was developed by a series of tunnels, the lower of which extends 300 feet through dacite to reach the vein. The upper tunnel is situated at the contact of the dacite with the andesite, which is here a fault contact. Such ore as can now be seen contains large amounts of arsenopyrite in columnar crystals, and also pyrite, galena, sphalerite, and minor chalcopyrite, but it is not known whether this ore is representative of what was the productive part of the deposit.

MINNESOTA MINE.

The Minnesota mine is situated on Clancy Creek, a short distance south of the old town of Gregory. It is one of the oldest located properties in the region; some development work has been done on it in recent years, but it was idle during 1911. The property is developed by a number of tunnels and an open cut. At the upper end of the open cut a small vein of copper-stained quartz is inclosed in much-altered andesite. The strike is east and west, and the dip is steep to the north. On the south wall, near the east end, there is altered granitic rock which contains small veins of tourmaline with quartz and pyrite. The upper tunnel is in altered granitic rock. The lower tunnel shows an irregular intrusion into the andesite of granitic rock, which where fresh appears to be a diorite. Slipping is shown along most of the contacts. The ore occurs in small veins, which cut both rocks but do not appear to follow the contact. They are of workable width in the granite only.

The ore minerals, consisting of galena, blende, pyrite, a minor amount of arsenopyrite, and rare specks of chalcopyrite, are inclosed in a small amount of quartz gangue.

¹ Fourteenth Ann. Rept. Inspector of Mines, Montana, 1902, p. 67.

NORTHERN PACIFIC MINE.

The Northern Pacific mine lies on the west side of Alta Mountain. The country rock is a highly flow banded andesite. The ore contains galena, pyrite, and sphalerite, in a gangue of manganiferous calcite holding fragments of brecciated andesite.

WICKES-CORBIN COPPER CO.'S PROPERTY.

The property of the Wickes-Corbin Copper Co. is situated a short distance southeast of Wickes in a small gulch known locally as Picnic Gulch. The principal piece of development work is the Bunker Hill tunnel No. 4, approximately 900 feet long. The prevailing country rock at the workings is a dark gray-blue andesite, well exposed on the west side of Picnic Gulch. On the east side of the gulch the andesite is intruded by granitic rocks belonging to the Boulder batholith and shows conspicuous evidence of thermal metamorphism. The summit of the ridge on the east of the gulch is occupied by an intrusive mass of aplite or alaskite, which in places is prominently porphyritic, owing to the presence of large phenocrysts of quartz and feldspar. As a rule it is thoroughly sericitized, approaching a fine-grained greisen in appearance, and it is almost impossible to obtain unaltered rock.

The Bunker Hill tunnel No. 4 is being driven to undercut an extensive outcrop of leached andesites exposed approximately 300 feet above the portal. A tunnel 275 feet above the Bunker Hill tunnel is 200 feet long and traverses leached andesites; drifts extending 50 to 100 feet in a north-south direction are more or less coated with chalcantite—crystallized copper sulphate—and with gypsum needles. The rocks contain disseminated pyrite, evidently cupriferous, veinlets of solid pyrite, and also some that are galena bearing. The rocks traversed in the lower or Bunker Hill tunnel are exceedingly jointed andesites, which are pierced by a vertical aplite dike, approximately 200 feet wide as exposed along the tunnel. The andesites are more or less pyritized throughout the length of the tunnel and are traversed by pyritic seams. Some weak and poorly defined irregular shear zones are encountered at various places and are veined with discontinuous quartz stringers carrying galena, sphalerite, chalcopyrite, and pyrite. The main lode, lying on the inner side of the aplite contact, is 4 feet wide but does not constitute pay ore. It is believed that the deposit exposed on the surface, if the dip is vertical, will be intersected in tunnel No. 4 at about 900 feet from the portal. If there is any secondary enrichment it can be predicted that it has taken place a short distance below the upper tunnel level, as all ore in the main crosscut is of primary character.

In the Tulare tunnel, on the east side of the gulch, considerable drifting has been done along irregular shear zones in the andesites.

In these workings there were encountered some masses of biotite andesite, a rock related to the dacites that occur in great volume west of Wickes.

BOULDER AND BASIN DISTRICTS.

LOCATION.

Boulder and Basin are situated on Boulder River. Boulder, a town of 800 population, is the county seat of Jefferson County. Little mining is in progress in the district adjoining it. Basin, founded in 1880, lies 8 miles west of Boulder; a concentrator for the treatment of Butte ores was built here because of the abundance of water. Cataract and Basin creeks enter Boulder River near Basin from the north and northwest; the roads that ascend the valleys of these streams render a large part of the Boulder Mountains tributary to Basin.

The Boulder Hot Springs are situated 2 miles south of Boulder. They have been carefully described in detail by Weed,¹ who has shown that the hot waters are in process of forming mineral veins filled with quartz, stilbite, and calcite, which contain small but appreciable amounts of gold and silver.

DESCRIPTIONS OF MINES.

ROBERT EMMET MINE.

The Robert Emmet mine lies at an elevation of 5,600 feet on the south side of the Wickes-Boulder divide near the road between those towns. It is electrically equipped and a shaft has been sunk to a depth of 470 feet, with levels at 200 feet and 350 feet, but these were not accessible at the time of visit. The vein occurs in the granite several hundred yards east of the contact of the granite and andesites, which are well exposed upon the divide; it is said to strike east and west and to average 5 feet in width. The ore in the upper level as seen on the dump consists of sphalerite, pyrite, chalcopryrite, and galena in a quartz gangue. The valuable constituents are silver and copper, together with a small amount of gold (\$2 to \$5).

AMAZON MINE.

The Amazon mine is situated on the west side of Boulder Valley, 4 miles north of Boulder. The mine was closed down during 1911, but its owners intend to reopen it. The country rock is a granite. The ore contains much sphalerite and galena, with a small amount of chalcopryrite and pyrite in a quartz gangue.

BALTIMORE MINE.

The Baltimore mine is situated on Boomerang Creek, 4½ miles northwest of Boulder. A small crew of men were employed on the property during 1911.

¹ Weed, W. H., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 227-255.

Two separate ore bodies have been exploited. The upper one is opened by tunnels 4, 5, and 6; the lower one by tunnels 1, 2, and 3. Tunnel 1, which enters the hill at an elevation slightly above the bed of Boomerang Creek, is the only one in which work was being done at the time of visit.

The general country rock in the vicinity of the mine is granite, but the principal workings are in intrusive masses of aplite, a light-colored granular rock consisting of orthoclase, quartz, and a minor amount of biotite. There have been encountered also some porphyry dikes of andesitic character, related to the dacites capping the granite on Sugarloaf Mountain, which lies a short distance southwest of the mine. The ore bodies that have been mined were short, irregular veins with numerous branches, but locally swelling to considerable dimensions. In tunnel 5 there remains a large body of ore, consisting mainly of black sphalerite inclosed in a coarse white quartz gangue. Galena, pyrite, and chalcopryrite are associated sulphides. Sphalerite transformed to covellite is found as a rarity. This ore body was too zincky to work formerly, and only the portions containing considerable lead were extracted.

The ore body developed in the three lower tunnels has been largely stoped out to the surface from above tunnel 2. In this tunnel the vein is approximately 130 feet long and is terminated at both ends by faults. The first 65 feet has been stoped out; the remainder of the vein consists of flinty gray and chalcedonic quartz, evidently too low grade to pay for extraction. In the winze between tunnels 2 and 1, 86 feet below, the vein is well shown. It stands vertical and ranges in width from 6 to 8 feet. The hanging wall is sharply defined, but the footwall is less well marked, the vein inclosing some aplite, reticulated with fine-grained siliceous veinlets. The gangue is a coarse white quartz irregularly mingled with dark flinty quartz and carrying a sparse amount of metallic sulphides. Pyrite is the principal sulphide, and sphalerite, galena, and chalcopryrite occur in minor amounts. The ore is stated to contain \$7 a ton in gold.

GRAY EAGLE MINE.

The Gray Eagle mine is situated at the head of Bishop Creek, a tributary of High Ore Creek. The lower or main working tunnel is 1,800 feet long, but only 1,000 feet are now accessible; it traverses both granite and aplite. The pit on the surface, however, is in andesite. The course of the vein is N. 75° W. The lower tunnel is approximately 200 feet below the pit, and a shaft inside the tunnel was sunk another 200 feet. Apparently there was one principal ore shoot, which was stoped out to the surface. The estimates of production show a considerable range, but half a million dollars' worth of lead-silver ore seems to be a moderate figure.

COPPER KING PROSPECT.

The Copper King prospect is situated 3 miles northeast of Basin in Hiawatha Gulch. The principal development consists of a tunnel drifted 125 feet along the vein. During 1911 a shaft was being sunk on the vein and attained a depth of 35 feet. Two men were employed.

The ore body is a narrow vein a foot thick at most, trending east and west, inclosed in granite walls. The ore is a quartz carrying tetrahedrite and a small amount of pyrite. The quartz is of coarse glassy character mingled with cryptocrystalline and chalcedonic phases. By sorting, a product containing 24 ounces of silver and \$1.60 in gold to the ton and running 94 per cent of silica is obtained. The ore is sorted so as to run high in silica, because it is shipped to the copper smelter for use as converter lining, and a bonus of 15 cents is paid for each unit in excess of 75 per cent of silica.

QUARTZ MASS NEAR BASIN.

A great mass of quartz is inclosed in granite 1 mile east of Basin alongside the track of the Great Northern Railway. This quartz mass was formerly of some economic importance; it was quarried and shipped to Butte as converter lining for the copper smelters.

The quartz mass is 200 feet in altitude from its top to the floor of the pit; most of it forms a sheer face of coarse solid white quartz absolutely devoid of any metallic sulphides; on the level of the pit it is 350 feet wide. Coarse quartz monzonite surrounds the quartz mass, but the actual contact is covered everywhere by loose material. The monzonite shows megascopically no noticeable alteration. In the tunnel, which is 100 feet below the pit, the main rock is a coarsely granular alaskite porphyry slightly pyritized. Only an insignificant amount of quartz is exposed in the tunnel. A noteworthy feature is that small quartz stringers, branching off from the larger masses and penetrating the porphyry, inclose numerous euhedral crystals of orthoclase up to three-fourths of an inch in length, forming a rock resembling a quartzose pegmatite.

EVA MAY MINE.

The Eva May mine is situated on Cataract Creek, 8 miles north of Basin. The mine is developed by a shaft 1,200 feet deep, with levels at every 100 feet down to the 600-foot level, and also at 800 feet and 1,200 feet. The general rock in the vicinity of the mine is a coarse gray quartz monzonite cut by intrusions of a tourmaline-bearing white aplite. The ore is a coarse white quartz carrying pyrite, chalcopyrite, galena, sphalerite, and tetrahedrite. Further, it is noteworthy that some of the ore contains considerable black tourmaline. An interesting fact is that the mine dump shows also considerable blue-gray cryptocrystalline quartz, but the significance of this or its

relation to the tourmaline-bearing quartz ore could not be determined on account of the inaccessible condition of the underground workings.

Concerning this mine Weed¹ says:

An example of the economic necessity of carefully observing secondary fractures and accompanying enrichment is shown by the Eva May mine, on Cataract Creek, near Boulder, Montana. In the early history of the mine much high-grade ore was found, consisting of pyrite, together with more or less galena, blende, and chalcopryite, the whole impregnated with scattered bunches of rich antimonial sulphides of silver. The vein is a large one and shows thick ore shoots of pyritic ore, but the bulk of this, away from the enriching fracture, is too poor to work.

An analysis of a concentrate of the pyritic ore, cited by Weed, shows 9.83 per cent of lead, 6 per cent of zinc, 4.56 per cent of copper, 0.1 ounce of gold, and 1.85 ounces of silver.

The King tunnel, which is being driven to hold some unpatented ground, is 450 feet in length and is drifted along a highly tourmalinic lode $2\frac{1}{2}$ to 3 feet wide. The principal sulphide is pyrite, with arsenopyrite, sphalerite, and galena in minor amounts. Sulphides are contemporaneous with the tourmaline and it is noteworthy that in comby veinlets of quartz the tourmaline fills the central portion of the veins.

UNCLE SAM MINE.

The Uncle Sam mine is an old property, from which in early days some 12,000 tons of ore were taken out and hauled to Wickes. This was said to carry from \$30 to \$90 a ton. Operations have recently been commenced to reopen the mine. A crosscut tunnel is being driven to intersect the lode at a depth of about 175 feet; the estimated length is 450 feet, of which 250 feet had been completed at the time of visit.

The country rock is aplite, forming a border between the main body of granite, which is encountered in the tunnel, and a capping composed of andesites. An aplite dike, 10 to 15 feet wide, with gouge on both contacts was crosscut in the tunnel. The vein is near the contact of the aplite with the overlying andesites; in fact the pits on the extension of the vein are in andesite. The andesites, or probably more accurately latites, are flow-banded varieties; they have been considerably metamorphosed by the intrusion of the granitic rocks and in consequence are not easily recognizable. They are light colored and because of their light color and highly developed flow banding have been regarded as rhyolites and phonolites.

The old workings took out a shoot of ore extending 80 feet east of the incline shaft and reaching a depth on the incline of 130 feet. The ledge is said to be 12 feet wide and the ore minerals are galena and sphalerite with subordinate tetrahedrite.

¹ Weed, W. H., *Genesis of ore deposits*, special publication Am. Inst. Min. Eng., 1902, p. 495.

WESTERN RESERVE MINING CO.'S MINE.

The Western Reserve Mining Co. owns the Hattie Ferguson mine on Cataract Creek, 6 miles from Basin. The mine was formerly worked by a shaft 140 feet deep, but a crosscut, now over 1,400 feet long, is being driven and is expected to cut the vein at a depth of 362 feet below the collar of the shaft. The country rock is aplite, which extends northward to the Sirius and Klondike mines, although a small amount of normal granite is encountered in this area. The aplite is somewhat porphyritic, and near the vein this texture is accentuated by the chalky appearance of the feldspar. The ore minerals are galena, pyrite, and sphalerite, and 40 per cent of the value is said to be in gold.

BUTTE AND PHILADELPHIA PROSPECT.

The Butte and Philadelphia prospect is situated on the flank of the group of peaks known as the Three Brothers and lies northwest of the south peak at an elevation of 7,800 feet. The property is reached from the south by the road extending up Basin Creek from Basin. Some machinery was installed and a small amount of development work was in progress during 1911. A series of three parallel veins traverses the granite, one of which is developed by 250 feet of tunnel. The strike is N. 80° W. and the dip 65° N. The ore occupies a 7 to 10 foot crushed zone in the granite. The metallic minerals are chiefly pyrite, with small amounts of galena and sphalerite, associated with very little quartz. Between the pyrite and the heavy zone of gouge that occurs along the hanging wall, there are in places slabs of galena 1 inch thick and from 1 to 2 feet in diameter, showing a banded structure.

BULLION MINE.

The Bullion mine lies at an elevation of 7,400 feet on the northwest side of Jack Mountain, 10 miles by road from Basin. A concentrator and smelter of 200 tons daily capacity was constructed and several thousand feet of drifts and tunnels run, but the property is now idle.

The country rock at the mine is mainly quartz monzonite, intruded, however, by small dikes and masses of tourmaline-bearing aplite. Near the ore the rock is much altered by sericitization and pyritization and is cut by irregular veins, carrying black columnar tourmaline, quartz, and pyrite. The ore minerals in order of decreasing abundance are pyrite, tetrahedrite, galena, sphalerite, chalcopyrite, and arsenopyrite, and are inclosed in a gangue of coarse white quartz. A second and later mineralization has affected the veins and is represented by a gray, flinty quartz carrying minor amounts of metallic sulphides. The ore therefore is of composite origin.

MORNING STAR MINE.

The Morning Star mine is situated on the west side of the valley of Basin Creek, half a mile west of Winters Camp. The ore body strikes east and west and consists of a quartz vein inclosed in a much-altered andesite. The metallic minerals are galena, sphalerite, pyrite, and chalcopyrite in small amount. The richest ore occurs in a 2½-inch streak, consisting principally of galena, and is reported to run 40 ounces in silver and \$3.80 in gold to the ton and 50 per cent of lead.

CUSTER MINE.

The Custer mine is situated 1 mile southeast of Basin at an elevation of 6,000 feet. The ore body is a wide quartz vein, in places attaining a width of 30 feet, traversing sericitized granite. The strike of the vein is east and west, but the pay streaks, which are generally under 1 foot in width, are very irregular in width and direction. The ore is a high-grade silver-lead carbonate, which is stated to carry 40 ounces in silver and \$18 in gold to the ton.

ALLPORT MINE.

The Allport Mining Co.'s property, consisting of 5 end-on-end claims extending northeast and southwest, is situated 4 miles south of Basin, at an altitude of 7,500 feet. The main development work consists of a shaft 110 feet deep and a number of short levels. During 1911 work was in progress on the 55-foot level, but the vein below this level is flooded with water.

The country rock is a coarse gray granite. On the 55-foot level the vein, which trends N. 36° E. and dips nearly vertical, is from 5 to 6 feet wide and consists partly of quartz and partly of granite. The wall rocks are much altered by sericitization and impregnation with pyrite. The vein on the 100-foot level is said to be 12 feet wide and to assay \$16 a ton in silver and gold across the face. The ore is a bluish-gray cryptocrystalline quartz, carrying mainly pyrite in small amount and some sphalerite.

On the northwest extension of the course of the vein some coarse-grained white quartz veinlets were seen that carried considerable tourmaline, but these were said to be valueless. These quartz-tourmaline veinlets have been brecciated and recemented by chalcedonic quartz.

RUBY MINE.

The Ruby mine is situated on Lowland Creek, 4 miles from its junction with Boulder River. The 10-stamp mill on the property is built near the stream at 6,000 feet altitude, but the mine lies half a mile southeast of the mill, at an altitude of 6,750 feet. By air line the Ruby mine is 14 miles north of Butte. The property was located in the seventies and surveyed for patent in 1888.

The production is estimated to be \$1,250,000—70 per cent in gold and the remainder in silver. Rich ore was sent to the smelter, and netted from \$17 to \$302 a ton in carload lots. The mine has been operated only intermittently, having several times been considered as worked out. In September, 1911, the mill was again started and commenced crushing a dump of some 1,200 tons of second-class ore which had accumulated during recent exploratory work.

The main shaft is situated at 6,750 feet altitude and was sunk to a depth of 400 feet. A crosscut tunnel intersects the shaft at 150 feet below the surface. The mine is now flooded with water below the 150-foot level.

The general country rock at the Ruby mine is dacite, or rhyolite, as it is better known locally. It lies in the heart of the great area of dacites that extends southward to Butte and forms Big Butte at that city. At the Ruby mine the original thickness of the superposed succession of dacite lavas and breccias was at least 2,500 feet. The dacite at the mine is a markedly porphyritic rock, showing numerous crystals of quartz and glassy striated feldspar embedded in a light-grayish groundmass of dense texture. In the vicinity of the mill the rock is prevailingly a dacite breccia.

The ore-bearing zone extends from the main shaft to the Columbia claim, a distance of several thousand feet, the general trend being S. 20° E. Within this zone the ore occurs in shoots, or more properly in parallel veins, dipping steeply westward and apparently disposed roughly in échelon fashion. The Ruby shaft was sunk on a shoot of ore which, as shown on the stope map, was 260 feet deep, 40 feet long, and 20 feet wide. The extreme length, which was 70 feet, was on the 200-foot level. This shoot of ore, or pipe, as it is termed locally, yielded \$600,000. The country rock in the vicinity of this shoot is extremely sheared and shattered. To the north the ore body is terminated by a southward-dipping fault zone, which is brecciated and mineralized through a width of 40 feet or more.

South of the Ruby shoot another vein was found, in which the productive portion was 170 feet long and 4 feet wide. The walls of this vein are generally well defined. A marked vertical undulation is a characteristic feature of the hanging wall. In places the vein is filled with fault breccia, some fragments of which are 20 inches long. Toward the north the fissure is apparently cut off by a cross fault dipping 45° S., although the fissure is here so small as hardly to be recognizable. The fissure is traceable by a well-defined footwall for a distance of 60 feet south of the productive portion, where it is terminated by a cross fault dipping south. It is not impossible that some of the cross faults are fractures contemporaneous with the major fissuring. The ore consists of angular dacite fragments cemented by quartz, calcite, and minor adularia. The adularia, where embedded

in quartz and calcite, is not easily distinguishable, but in places forms crystals up to one-fourth inch in diameter. Its identity was established chemically and optically. The quartz is commonly clear, glassy, and drusy, but where it is solid it is of compact saccharoidal texture. Some of the siliceous veinlets show a porcelain-like texture, but such cryptocrystalline quartz is far less common at the Ruby mine than at the surrounding properties. The sulphides, which are confined to the gangue material that cements the dacite fragments, comprise pyrite, argentite, and possibly others that because of their fine subdivision are not readily recognizable. Native silver is common locally. The grade of the ore decreases with increase in size of the dacite fragments filling the fissure.

The workings extend on the southeast into the Columbia claim, which was recently acquired by the owner of the Ruby mine. The Columbia vein is developed by a number of drift tunnels, one of which now connects with the Ruby workings. A pronounced joint system, trending N. 20° W., occurs in the Columbia tunnels and appears to have governed the trend of the ore body. The Columbia vein represents a zone of brecciation 12 feet or more wide. The individual fragments of brecciated dacite show little movement or deorientation, and the filling of the vein consists for the most part of angular fragments of dacite coated with a crystalline crust of quartz. In places, however, there is considerable white quartz unmixed with country rock. Some of this quartz is identical in appearance with that of the Empire and other veins of Marysville; that is, it is of lamellar habit and shows irregular pyramidal hollows lined with small glassy quartz crystals. Such ore is of low grade, carrying \$4 to \$5 a ton in gold. The former owner took out only a rich streak along the hanging wall.

KIT CARSON MINE.

The Kit Carson mine is situated on Lowland Creek near the stamp mill of the Ruby mine. The production is said to have been \$100,000 in gold and silver. The property has in recent years been worked by lessees, but was idle during 1911.

The main development is a drift tunnel entering the hill from the level of the stream bed. It is approximately 325 feet long and trends N. 10° E. The country rock is porphyritic dacite. At the face of the tunnel is seen 5 feet of highly brecciated porphyry, in which the fragments are irregularly traversed by chalcedonic and porcelainoid veinlets. The west wall (footwall?) is marked by a zone of soft, white clay. Locally, as shown along the tunnel, the hanging wall seems to have been determined by a platy structure parallel to the flow banding of the dacite.

Material on the dump shows that the dacite was netted with veinlets of silica carrying pyrite. Drusy crystalline, chalcedonic, and porcelainoid varieties of silica are intimately associated together.

The feldspars of the dacite have been altered to chalky spots, in appearance strongly suggestive of kaolin but which prove under the microscope to be cryptocrystalline aggregates of sericite. The quartz veinlets when examined microscopically are found to contain minute crystals of adularia.

MEMPHIS PROSPECT.

The Memphis prospect is on Lowland Creek, half a mile upstream from the stamp mill of the Ruby mine. The geologic features are similar to those of the Kit Carson mine. The dacite is cut by irregular veinlets of cryptocrystalline silica, carrying a little pyrite in cubes and pentagonal dodecahedrons. In addition to the dark gray-blue quartz the porcelainic variety is common.

ELKHORN DISTRICT.

LOCATION AND HISTORY.

The Elkhorn district forms the southeast corner of the region considered in this report. The economic importance of this area has depended almost wholly on the Elkhorn mine, around which grew the town of Elkhorn.

The town of Elkhorn, situated at an altitude of 6,500 feet, lies 12 miles northeast of Boulder, which is on the Butte branch of the Great Northern Railway. It is connected with Boulder by a branch line operated by the Northern Pacific Railway, which runs three trains a week.

The district was prospected before 1870 but did not attain prominence until after the discovery of the Holter lode in 1875, on which was founded the great mine subsequently known as the Elkhorn mine. This property was worked nearly continuously until 1900, when it was regarded as worked out and sold for a small sum, practically for the value of the machinery and equipment. The new owners commenced to rework the old dumps and to reopen the mine in 1901; since 1906 the mine has again been in continuous operation.

STRATIGRAPHIC GEOLOGY.

Elkhorn lies on the eastern margin of the Boulder batholith. The geology here is far more complex than at any other district in the region, owing to the number of sedimentary formations and to the abundance and variety of igneous intrusions. The details, however, have been ably worked out by Weed and must be sought in his report on the district.¹ The purpose of the present report is to show the relation of the ore deposits at Elkhorn to the mineralization of the province as a whole.

¹ Weed, W. H., *Geology and ore deposits of the Elkhorn mining district, Jefferson County, Mont., with an appendix on the microscopical petrography of the district by Joseph Barrell*: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, pp. 399-549.

The sedimentary rocks comprise mainly a series of Paleozoic limestones, shales, and quartzites, overlain in angular accordance by a series of Mesozoic sandstones, shales, and impure limestones, all highly altered by contact metamorphism. Overlying the Mesozoic rocks are a bedded series of andesitic breccias, tuffs, and lavas, which make up the summits of Elkhorn and Crow peaks, the culminating points of the district.

The oldest rock of the district is the metamorphosed shale to which Weed has applied the name Turnley hornstone. This is regarded as the local metamorphic equivalent of the Spokane shale of Algonkian age. The lowest formation of the Paleozoic is a white quartzite, 125 feet thick, which is correlated with the Flathead quartzite of Middle Cambrian age. Above this formation is a succession of limestones and shales, ranging in age from Cambrian to Carboniferous, to which various local names have been applied by Weed. Above these rests the Madison limestone of lower Carboniferous age, a massive-bedded white limestone aggregating 1,900 feet in thickness. At Elkhorn it is coarsely crystalline, owing to the thermal metamorphism exerted by the various igneous intrusions. The Quadrant quartzite (of probable Pennsylvanian age) overlies the Madison and consists of quartzites and lime-silicate hornstones totalling 382 feet in thickness.

The Mesozoic rocks overlie the Paleozoic, as already stated, in angular accordance. They are best exposed on the southwest spur of Crow Peak, whence they were termed by Weed¹ the Crow Ridge series and were regarded as including rocks of Jurassic and Cretaceous age, with which Stone agrees.² Weed's measured section shows a thickness of 1,680 feet between the underlying Quadrant quartzite and the overlying andesites.

The andesitic rocks at Elkhorn Peak are predominantly tuffs and breccias. The breccia bed at the base of the series contains angular blocks up to a foot in length. According to Weed,³ the andesitic lava flows, with tuffs and breccias at the bottom, lie on an erosion surface and terminate the series of Mesozoic sediments on Crow Ridge. At the point where the section was measured the actual contact, however, is hidden by talus, so that the existence of an erosion surface and its position in the stratigraphic column are matters of inference and not of observational fact. Certain it is, however, that the andesitic breccias and tuffs rest in angular accordance on the sedimentary rocks below them. It is probable that here as elsewhere in the region the andesites were folded at the same time as the underlying sedimentary rocks.

¹ Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, p. 440.

² Stone, R. W., Geologic relation of ore deposits in the Elkhorn Mountains, Mont.: Bull. U. S. Geol. Survey No. 470, 1911, p. 82.

³ Op. cit., p. 441.

Conspicuous features of the geology of Elkhorn are the marble cliffs on the western flank of Elkhorn Peak. They are masses of coarsely crystalline marble intercalated in the andesites and form bold cliffs of brilliant whiteness at the head of Elkhorn Gulch. Weed¹ says: "These inclusions are clearly blocks torn off from the underlying Madison limestone and borne into their present position by the force of the ascending magma." As the inclusions are not fossiliferous the reference to the Madison limestone was probably based on lithologic similarity. Two marble masses are known, the larger of which is 125 feet thick and 3,000 feet long. When this immense size is considered, together with the facts that the andesites below the limestone are predominantly tuffs and breccias and that the limestone is at least 1,000 feet hypsometrically above the nearest outcrop of the Madison limestone, this explanation seems inherently improbable. An alternative explanation, involving less catastrophic processes, is suggested by the fact that fossiliferous fresh-water limestone was found interstratified with the andesites southwest of Elliston. It therefore seemed probable that the supposed inclusions at Elkhorn were merely highly metamorphosed lenses of limestone interstratified with the andesitic series. To test this hypothesis the upper and lower contacts of the marble masses were carefully examined. The larger marble stratum was found to be overlain by a heavy stratum of coarse andesitic breccia and to be underlain by a thin bed of what appeared to be a banded tuff approximately 2½ feet thick. All the rocks are obviously highly metamorphosed owing to the proximity of quartz monzonite and aplite intrusions. The rock beneath the limestone is found in thin section to be composed of andalusite, biotite, plagioclase, orthoclase, and quartz. The texture is typical of hornfels, and the andalusite, which constitutes 25 per cent of the rock, is developed in large irregular prismatic individuals of spongiform or poikilitic habit. Certain of the larger plagioclase particles appear to be of fragmental origin. The abundance of andalusite seems to bear directly on the point at issue; it proves that the material directly below the limestone mass was highly aluminous and indicates that it was probably an argillaceous tuff.

Certain small masses of limestone intercalated in the andesitic series afford even stronger evidence that they are merely interstratified lenses in the andesitic series. Some are underlain by undoubted tuff, which is found to consist under the microscope of irregular angular particles of plagioclase and fragments of various porphyritic andesites embedded in an extremely fine grained matrix. At the altitude of 8,750 feet, near the head of Elkhorn Gulch, a band of finely crystalline limestone 8 feet thick rests on a stratum of coarse breccia 20 feet thick. It is to be noted that if the limestone masses

¹ Op. cit., p. 449.

were floated up by the magma they would be underlain by massive andesite, which would in all probability show some small intrusive tongues extending into the limestone.

INTRUSIVE IGNEOUS ROCKS.

The intrusive igneous rocks include a series of granular rocks and porphyries that were injected prior to the invasion of the region by the quartz monzonite of the Boulder batholith. They include the gabbro of Black Butte (which is of interest because Weed sees in it the source of the metals in the Elkhorn deposit), diorite, diorite porphyry, and quartz diorite porphyry. All are distinct and easily recognizable rocks. They were followed by the granite or quartz monzonite, which is remarkably similar in appearance and composition to the rock at Butte on the western margin of the batholith. Succeeding this came extensive injections of aplite.

CONTACT METAMORPHISM.

The intensity of contact metamorphism and the variety of minerals produced have been greater at Elkhorn than at any other locality in the region. Moreover, the phenomena are of such a character as to appeal to the eye, and the mineralogic changes that have ensued during metamorphism can be determined, in part, at least, without recourse to microscopic analysis. In this respect the district presents a strong contrast to the Marysville district, where the metamorphosed rocks consist predominantly of hornstones of aphanitic texture and of correspondingly obscure character to the eye.

The scapolitic and andraditic metamorphism of the calcareous (?) andesite breccia above the marble stratum on Elkhorn Peak, the andalusite hornfels below it, and the recrystallization of the andesites have already been described (pp. 27-28).

Barrell concluded, as a result of his study at Elkhorn, that "even under the most intense metamorphism the carbonic acid is not expelled from the limestone except by the presence of silica and the other impurities which accompany it."¹ It was shown mathematically that during metamorphism a notable reduction in volume, or increase in porosity, must result. For the Dolcoath stratum a shrinkage of 50 per cent was computed. But these mathematical results were unsupported by chemical analyses and the computations were based on the unverified assumption that the garnet produced during metamorphism is invariably a pure grossularite. Iron-bearing garnets, however, seem, according to the present hasty investigation, to be the prevalent variety at Elkhorn. Some are certainly andradite, especially those occurring in the contact-metamorphic ore deposits, but others are probably intermediate varieties.

¹ Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, p. 549.

The following analyses made for Weed in 1906¹ show the actual chemical composition of garnetized limestone occurring 2,300 feet north of Black Butte at Elkhorn. No. 135 (analysis I) is the analysis of a rock composed of a closely packed assemblage of subhedral brown garnet grains, interspersed with sporadic patches of calcite containing euhedral garnets. Under the microscope the rock is found to consist predominantly of brown garnet. Zonal structure and optical anomalies are common in the garnet, and a dodecahedral parting is well developed. The cores of many of the garnets have apparently shrunk slightly away from the peripheral zones. By the immersion method the refractive index is found to exceed considerably 1.79 (that of grossularite is 1.744 and andradite 1.85). Calcite, quartz, chlorite, and amphibole occur interstitially. No. 147 (analysis G) is the analysis of a garnet rock of dense massive texture. Microscopically the rock proves to consist largely of garnet poikilitically inclosing diopside, calcite, feldspar, titanite, and apatite.

Analyses of garnet rock, Elkhorn, Mont.^a

	No. 135.	No. 147.
SiO ₂	36.91	40.31
Al ₂ O ₃	6.54	12.11
Fe ₂ O ₃	19.43	8.67
FeO.....	.67	.40
MgO.....	1.07	2.65
CaO.....	31.09	33.61
Na ₂ O.....	Trace.	.79
K ₂ O.....	.18	.12
H ₂ O-.....	.70	.23
H ₂ O+.....	1.57	.22
TiO ₂	Undet.	.78
CO ₂	1.91	None.
P ₂ O ₅	Undet.	.69
	100.07	100.58

^a Analysis No. 135 by E. C. Sullivan; No. 147 by W. T. Schaller.

The approximate mineral composition, calculated from the chemical analysis in accordance with microscopic diagnosis, is as follows:

Approximate mineral composition of garnet rock, Elkhorn, Mont.

	No. 135.	No. 147.
Andradite.....	61.50	27.43
Grossularite.....	22.50	52.70
Diopside.....		15.75
Calcite.....	4.30	
Quartz.....	4.92	
Chlorite.....	4.20	
Feldspar.....		1.08
Titanite.....		1.96
Apatite.....		1.55
	97.42	100.47

¹ Listed by F. W. Clarke, as analyses G and I, in Bull. U. S. Geol. Survey No. 419, 1910, p. 92; the description of the rocks is hitherto unpublished.

These analyses and computations show clearly enough the considerable range in composition of the garnet rocks produced during metamorphism; nevertheless, in the two rocks under discussion, there are no macroscopic features that would serve to distinguish surely the iron-rich from the lime-rich garnet rock.

ORE DEPOSITS.

A wide variety of ore deposits is found within the small area of the Elkhorn district. Several genetically distinct types are included: The magmatic sulphide ore body at the Golden Curry mine, the auriferous contact-metamorphic lode at the Dolcoath mine, the contact-metamorphic bodies of magnetite ore the tourmaline-bearing galena-quartz ore at the Queen mine, and the lead-silver replacement deposit at the Elkhorn mine.

The great ore body of the Elkhorn mine has overshadowed all others in economic importance, and Weed's report on the district is, as he himself states, essentially a report on the Elkhorn mine. From the present writer's point of view, however, other of the deposits are also of much interest.

The magmatic sulphide body, the details of which are given under the description of the Golden Curry mine, is an ore mass consisting of a mixture of pyrrhotite and chalcopyrite intergrown with augite. Surrounding the sulphide body and grading into it is a zone of dark heavy rock of fresh appearance and of even-grained granitic texture, which proves on microscopic examination to be a pyrrhotitic augite diorite. This rock in turn grades laterally outward into quartz monzonite, composed of plagioclase, orthoclase, quartz, biotite, and hornblende, which is the normal country rock. The sulphide mass has yielded 2,000 tons of ore, carrying \$4 in gold, 35 per cent excess iron, and 2 per cent copper.

The ore body at the Dolcoath mine is a stratum 12 to 18 inches thick, composed essentially of garnet (andradite), diopside, calcite, and epidote. The rock is commonly of dense massive texture, but in proportion as the amount of calcite increases, the garnet and epidote show more complete crystallographic development. Sulphide and telluride of bismuth, carrying gold, together with chalcopyrite, constitute the ore minerals and occur in small amount, intergrown both with the silicates and the calcite. That the garnetization and the recrystallization of the calcite took place nearly simultaneously is proved by the fact that perfect crystals of garnet occur completely isolated in the midst of large crystalline patches of calcite.

According to Weed, the Dolcoath ore stratum is composed of nearly equal parts of diopside and grossularite with calcite. The garnet, however, according to the present examination, is not grossularite but is an andraditic variety. Weed, following Barrell, has suggested

that the Dolcoath ore stratum represents a bed of limestone rendered porous by contact metamorphism and subsequently impregnated by metalliferous solutions,¹ which also brought in the calcite. This is an exceedingly plausible a priori conception, but the field evidence, as shown by the simultaneous crystallization of the garnet and the calcite, does not support it. Furthermore, if the garnet is largely andradite instead of grossularite, the accuracy of the mathematics employed in calculating the hypothetical porosity produced during contact metamorphism is seriously impaired.

On the north side of Elkhorn Peak occur bodies of iron ore near the contact of the large limestone stratum and the underlying andesite. The iron ore consists principally of magnetite associated with andradite. It has been mined to some extent for a flux. The magnetite is mainly intergrown with the garnet but is also present as thin strings and quartz-magnetite veinlets traversing the garnet rock. The garnet, as determined by the immersion method, has a refractive index considerably higher than 1.79, indicating its andraditic character. Locally axinite is found in coarse-bladed masses, some as large as a fist; some of it incloses euhedral crystals of garnet. Other minerals occurring in the ore bodies in lesser amounts are specular hematite, pyrite, chalcopyrite, and epidote. The deposits are extensively oxidized, and much soft iron oxide, in part derived from the andradite, is present, obscuring the geologic relations. The ore bodies are doubtless largely replacements of the limestone, but it is not improbable that the underlying andesite is also considerably garnetized or otherwise metamorphosed in a manner similar to that of the andesite breccia overlying the great limestone stratum of Elkhorn Peak.

The ore body at the Queen mine is the only representative of the tourmalinic class of deposits in the Elkhorn area. It is an argentiferous galena-quartz ore carrying tourmaline. Arsenopyrite, which is a constant associate of tourmaline the world over, occurs in this deposit but is found nowhere else in the Elkhorn area.

The premier ore deposit of the district has been that of the Elkhorn mine. By 1900 it had produced 8,902,000 ounces of silver, 8,500 ounces of gold, and 4,000,000 pounds of lead. The ore body consists essentially of argentiferous lead ore replacing dolomite beneath the arches of a hanging wall of hornstone. In comparison with the other ore bodies, one of the most interesting features of the Elkhorn deposit is the complete absence of metasomatic gangue minerals. The other deposits of the district show such characteristic minerals as andradite, diopside, epidote, axinite, and tourmaline all indicative of high-temperature origin—but this, the largest and most productive ore body of the Elkhorn district, is devoid of any evidence that it was formed under conditions of high temperature.

¹ Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, p. 458.

DESCRIPTIONS OF MINES.

ELKHORN MINE.

The Elkhorn mine is opened by an incline 2,300 feet long, attaining a vertical depth of 1,439 feet. During 1911 work was in progress on a large number of levels, from those near the surface down to the 2,300-foot level. About 175 men were on the pay roll, but a large number of these were engaged in surface work. All ore from the mine is washed and sorted into milling, shipping, and waste rock. The old dumps are being reworked and yield 5 per cent of their content in milling and shipping ore.

The geologic features of the Elkhorn mine have been described in detail by Weed, so that a brief outline is all that is necessary here. According to Weed:¹

The ore deposit does not constitute a true vein, though commonly spoken of as a vein or lode. The ore occurs in two principal shoots lying on the under side of folds—i. e., in the saddle of the folds—and conforming to the dip of the stratified beds in which they occur. These ore bodies are found along a bedding plane between indurated shale (hornstone) and dolomitic marble. This contact plane was followed in mining and has commonly been spoken of as the lode. Although there has been some slipping and movement along this plane, the contact is not mineralized, nor does it show any vein quartz or other lode material except in the steeply pitching arches underneath which the ore bodies occur. The ore deposits consist of more or less irregular bodies of rudely lenticular cross section lying against the hanging-wall hornstone, and as isolated masses forming so-called “chamber” deposits in the underlying dolomite.

The hanging-wall ore bodies consist of solid quartz² carrying galena, tetrahedrite, pyrite, and blende; the footwall bodies consist mainly of replacement masses of galena, sphalerite and pyrite in the dolomite beneath the hanging-wall hornstone.

At the time of Weed's examination the ore deposit was supposed to have a definite footwall—a thin stratum of argillaceous limestone occurring about 35 to 50 feet from the hanging wall, as measured along crosscuts into the footwall country. This is now known as the “40-foot contact.” It is particularly well shown on the 350-foot level south; where unsheared, it consists of a somewhat argillaceous stratum averaging 3 inches in thickness. It swells and constricts and has evidently been a locus of movement. The dolomite above and that below this stratum seem to be alike. The new owners of the Elkhorn mine, who acquired the property in 1899 after it had been regarded as worked out, have explored the footwall country below the 40-foot contact and have discovered other ore bodies. They have found two other “contacts,” known as the 80-foot and 160-foot contacts. In other words, the thickness of the ore-bearing zone has been found to be 160 feet instead of 40 feet (or 80 and 20 feet, if

¹ Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, pp. 470-471.

² Aragonite in fibrous aggregates over an inch long was noted (and verified chemically) by the writer to be intergrown with quartz from the 1,750-foot level.

measured normal to the dip of the stratification). The 80-foot contact is apparently a stratification plane and is not particularly well marked. The dolomite shows no recognizable change above or below this plane. The 160-foot contact is even more feebly marked than the 80-foot contact.

The ore masses, which after extraction are represented by extremely irregular caverns and crooked pipes, are known as first, second, or third contact bodies, according to the contact on which they were discovered. Many of them extend by exceedingly devious courses back to the hanging-wall hornstone, or slate, as it is known locally. Great ore masses have been found whose major dimensions cut across the bedding of the dolomite. In this respect the Elkhorn deposit departs strongly from the saddle-reef type of ore body, with which Weed has identified it, but in the broader feature—the localization of the ore shoots beneath anticlinal arches, so clearly shown on Plate LVII of Weed's report—it is in striking accord with the saddle-reef type.

GOLDEN CURRY MINE.

GENERAL FEATURES.

The Golden Curry, or Jacquemin mine, as it is shown on the Elkhorn map,¹ is located near the intrusive contact of the quartz monzonite and a series of thin-bedded limestones, to which Weed gave the name Starmount limestone. The limestones have been highly metamorphosed into various lime silicates, forming dark-colored banded hornstones of dense texture. Locally heavy garnet rocks have been produced and in places the garnet (probably andradite) is coarsely crystalline, especially near calcite patches; where the calcite has been partly leached out by weathering a porous rock is produced, showing druses lined with crystalline garnet. Some of the garnet rock contains a little intergrown chalcopyrite and is said to constitute ore. Above the main pit of the mine are found considerable amounts of a somewhat notable rock composed of garnet and opal. Some of it consists of garnets set in a matrix of conchoidally fracturing opal of light-yellowish color. Under the microscope a specimen of the garnet-opal rock was found to consist of garnet, diopside, calcite, opal, and cryptocrystalline silica, in part spherulitic. The evidence seems to show that the garnet had been fractured, crushed, and recemented by opal and cryptocrystalline silica. It is to be noted that the cryptocrystalline silica mixed with yellowish opal produces a "hornstone" indistinguishable by the eye from the "hornstone" due to a mixture of contact-metamorphic silicates.

The main workings of the mine consist of a large open pit from which some 50,000 tons of iron ore have been mined, mainly as a

¹ Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, Pl. XLV.

flux for the smelters. The ore averaged 40 per cent iron and carried from \$4 to \$5 a ton in gold. The pit is located at the immediate contact of the metamorphic rocks and the granite, and at first inspection it might appear that this deposit of iron ore was of the same type as those so common at many granite and limestone contacts in the Western States, namely, a deposit of magnetic iron ore developed in the limestone during contact metamorphism. In this deposit, however, the magnetite does not occur intergrown with the contact-metamorphic silicates but forms veins in the granite itself, some of the veins attaining a thickness of 3 feet. In some of the underground workings beneath the main pit, namely in tunnel No. 1, there are found some lodes of heavy red jasper-like material which chemical analysis shows to be a hydrous ferric silicate.

Partial analysis of iron ore from the Golden Curry mine, Montana.

[J. G. Fairchild, analyst.]

Fe ₂ O ₃	59.23
SiO ₂	31.37
H ₂ O (loss on ignition).....	8.40
	<hr/>
	99.30

This material is also mined as iron ore. It contains considerable martite and rarely some pyrite. The analysis above, however, represents only the homogeneous, conchoidally fracturing portion.

In a raise above this lower tunnel a large chamber of ore inclosed in granite has been stoped out. This ore presents many features similar to the pyrrhotite body about to be described. It consists of pyrrhotite, magnetite, and subordinate chalcopyrite intergrown with brown-green augite. In places pyrrhotite predominates, in others magnetite predominates, and locally they are commingled in equal proportions. This body of ore is bounded on one side by a thick zone of gouge, along which occurs iron-bearing jasperoid similar to that of which the analysis has been given.

These iron deposits are unconnected with the body of sulphide ore described below. The Golden Curry mine affords a striking illustration of the fact that the ore at a single mine may be of very diverse origin and mode of occurrence, at least four kinds being recognizable at this property: Magmatic, contact-metamorphic, magnetite veins in granite, and hydrous ferric silicate masses apparently formed by downward-moving waters that derived their iron from the oxidation of sulphide masses.

THE PYRRHOTITE ORE BODY.

A mass of sulphide ore was encountered during the underground exploration of the mine 250 feet southwest of the magnetite deposits found at the contact. This body of sulphide was wholly inclosed in the granite and isolated from the other ore deposits. It is elliptical

in shape, its dimensions being: Length, 100 feet; maximum width, 18 feet; and it has been stoped upward to a height of 10 or 12 feet. From it were extracted 2,000 tons of ore running \$4 in gold, 35 per cent excess iron,¹ and 2 per cent in copper. The ore consisted of a mixture of pyrrhotite and chalcopyrite in a gangue of pyroxene. Under the microscope it is found that the ore is composed essentially of the monoclinic pyroxene augite intergrown with the two sulphides. The augite is in places intergrown with a small amount of pleochroic brown hornblende of the kind usually found in deep-seated igneous rocks. Other silicate minerals found more rarely are biotite, plagioclase feldspar, orthoclase, and quartz, but these constitute an insignificant proportion of the whole. Texturally the augite forms an allotriomorphic assemblage of anhedral grains. The sulphides, which are mutually intergrown, occur interstitially between the augite grains or irregularly intergrown with them. It is a noteworthy fact, however, that although the augite is usually anhedral it shows, where adjoined or surrounded by sulphides, a closer approximation to its idiomorphic outlines. The contours are as a rule somewhat rounded and smoothed by corrosion, and the sulphides often form distinct embayments into the augite which resemble those so common in the magmatically resorbed quartz phenocrysts of rhyolitic rocks. On account, however, of the general tendency of the sulphides and the pyroxene to be intergrown in allotriomorphic fashion, exactly as in gabbroic rocks, the microscopical evidence based on the texture alone is perhaps not conclusive as to the primary igneous origin of the sulphides.

Surrounding the sulphide mass and grading into it is a body of dark, heavy rock of fresh appearance and even-grained granitic texture. Under the microscope this rock is found to consist of approximately equal amounts of pyrrhotite, augite, and plagioclase of the composition $Ab_{65}An_{35}$. The texture is allotriomorphic granular and the rock may be appropriately termed a pyrrhotite-augite diorite. This rock is, however, somewhat variable in composition, in places containing considerable primary quartz, but the essential feature in all places is the dominant amount of augite. The rock grades laterally outward from the ore deposit within a distance of 6 to 12 feet to a quartz monzonite of normal appearance. Such rock 12 feet from the ore lens consists of a hypidiomorphic granular assemblage of plagioclase, orthoclase (the two feldspars occurring in approximately equal amounts), quartz, biotite, and hornblende. A specimen taken 50 feet from the periphery of the ore lens shows essentially the same features, the only noticeable difference being that the plagioclase feldspar is slightly more calcic, having the composition corresponding to $Ab_{55}An_{45}$. A chemical analysis of the quartz monzonite (No. 5, p. 30) is available;

¹ That is, iron in excess of silica; excess iron is the basis of the price paid by the smelter.

the specimen was taken 1 mile from the contact at this locality, and is typical of the general rock mass in which the ore body is inclosed.

To summarize briefly, the primary igneous origin of the sulphides is indicated by the following facts:

1. All the rocks, including those composing the ore body and those surrounding it, show an entire lack of hydrothermal alteration, such as the development of sericite, chlorite, carbonates, or other secondary minerals. They are fresh, unaltered rocks in which the ferromagnesian minerals are notably lustrous and the feldspars are clear and vitreous.

2. The textural relation of the sulphides to the augite, as displayed by the tendency of the pyroxene to show idiomorphic boundaries against the sulphides. This is a feature not easily explainable other than by the hypothesis of an igneous origin.

3. The marked differentiation that has taken place in the magma concurrently with the segregation of the sulphides. This is expressed mineralogically by the decrease of orthoclase, quartz, and biotite and the concurrent increase in ferromagnesian mineral as the ore body is approached. Instead of hornblende or biotite, however, it is augite that appears in the ore body.

In conclusion, the important features of this deposit as a member of the class of magmatic ore bodies are: (1) That it has segregated from a comparatively acidic rock; other pyrrhotite-chalcopyrite bodies of this type have separated from magmas of gabbroic composition; (2) its relatively high gold content, which is unusual, as most magmatic ore bodies are poor in gold.

QUEEN MINE.

The Queen mine lies 2 miles south of Elkhorn. It was worked to a depth of 500 feet by a shaft 300 feet deep and by winzes extending 200 feet deeper. The property has furnished a considerable quantity of ore, but no work has been done on it during the last 10 years.

The ore body is situated at the contact of quartz diorite porphyry and limestone and formed, as seen from the surface, an elliptical chimney measuring approximately 25 by 50 feet. The ore is a coarse vitreous white quartz of drusy and vuggy texture. Galena is the principal sulphide and is the mineral that gave value to the ore. Other sulphides present are pyrite and black sphalerite, but they are not common. The quartz contains a fair amount of black tourmaline in nests and groups of delicately radial structure. In places the galena is pierced by acicular tourmaline. Some altered porphyry found on the dump is thickly studded with well-crystallized arsenopyrite; galena is locally intergrown with the arsenopyrite.

The ore of the Queen mine was a silver-lead ore and is stated to have averaged from \$10 to \$15 a ton.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

BULLETIN 528

GEOLOGY AND ORE DEPOSITS
OF
LEMHI COUNTY, IDAHO

BY
JOSEPH B. UMPLEBY



WASHINGTON
GOVERNMENT PRINTING OFFICE
1913

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OUTLINE OF REPORT.

Lemhi County, situated in the east-central part of Idaho, has until recently been difficult of access. With the extension of the railroad to Salmon in 1910, mining activity in parts of the area took on new life.

Placer gold was discovered at Leesburg in 1866, and soon thereafter lode deposits were recognized. Lead-silver deposits were worked actively in the eighties, but not until the advent of the railroad did this industry reach its maximum importance. The total production of the county is about \$20,000,000, two-thirds of which has come from gold, three-fourths of the remainder from lead, about \$40,000 from copper, and the rest from silver.

Lemhi County is a high mountainous area marked by broad, level-topped divides generally separating deep, narrow valleys. Near the close of the Eocene epoch the area was elevated from a lowland of moderate relief to a plateau about 8,500 feet above the sea. Remnants of this surface constitute the summit areas of the present day, lying in large part 3,000 to 4,000 feet above the adjacent valleys. Glaciers covered the highland tracts during Pleistocene time and extended down the larger valleys to elevations of 7,000 feet, rarely to 6,000 feet.

The basement rock is a gneissoid granite of Archean age which outcrops in the northwestern part of the area. Unconformably above it is a thick and widespread series of Algonkian schists, slates, and quartzites. These were mapped as a single unit, but it is thought probable that they could be subdivided to correspond with the Prichard slate, Revett quartzite, and Wallace formation of the Cœur d'Alene section. Formations of Paleozoic age are confined to the southeastern part of the county. They rest unconformably upon the Algonkian and consist of Cambrian quartzite, Ordovician, Silurian (?), and Devonian dolomitic limestones, and Mississippian limestone, in all possibly 6,000 feet of beds.

Next in order of age are large batholithic masses of granite, outliers of that great intrusive mass which crops out continuously over more than 20,000 square miles in central Idaho. Locally this intrusion corresponds with quartz diorite, and more commonly with quartz monzonite, but in most places in Lemhi County it approaches closely

to the composition of normal granite. A study of the physiographic history of central and eastern Idaho and of the sedimentary record of adjacent areas leads to the belief that the granite was intruded at about the close of the Cretaceous period. During Miocene time thick lacustrine deposits accumulated in valleys which were developed after the elevation of the Eocene erosion surface.

Dikes appear in all parts of the area, but are most numerous in the vicinity of granite outcrops. Tertiary lavas, both older and younger than the lacustrine deposits, extend in a broad belt from a point near Lemhi Pass southwestward beyond Parker Mountain.

The ore deposits of Lemhi County may be grouped as gold placers and lodes, lead-silver veins and tabular replacements, copper-bearing gold veins, cobalt-nickel deposits, and tungsten-bearing veins. Two epochs of mineralization are recognized—the older late Cretaceous or early Eocene, the younger late Miocene or early Pliocene. All the deposits, except a small group of gold-silver veins, belong to the earlier epoch. Important placer deposits occur about Leesburg, on Moose Creek, and along some of the streams which flow from the Beaverhead Mountains. Lode deposits, on the other hand, are widely distributed in the county, each of the nineteen mining districts containing several.

Gold-bearing veins are inclosed in many types of rock in Lemhi County, but few of them are far distant from rocks of the granite-rhyolite family. The gold veins are of two distinct ages. The younger veins are found in the Gravel Range and Parker Mountain districts, where they are inclosed in eruptive rocks, principally rhyolites, and in the Blackbird district, where they are associated with rhyolite dikes. In general these veins are strong fissure fillings characterized by cryptocrystalline quartz, lamellar calcite, and small amounts of adularia, chalcedony, and opal. They present a banded structure parallel to the walls. Metallic minerals, nearly always of microscopic size, are distributed through the ore in dark crimped bands of dull to submetallic luster. Pyrite is the only metallic mineral recognized, but a blue-black fine-grained mineral of metallic luster is even more abundant. Satisfactory chemical analysis of this material was not possible, but the presence of a strong trace of selenium was established. These veins were promising near the surface but have not proved profitable in depth.

The most important gold veins are of late Cretaceous or early Eocene age and are widely distributed in the northern, central, and western parts of the county. They are predominantly veins of coarse-textured, clear-white quartz, along which ore shoots occur at irregular intervals. Auriferous pyrite is the characteristic ore mineral, but with it may be small amounts of chalcopyrite, galena, sphalerite, and in a few places pyrrhotite and magnetite. Locally the metallic

minerals are present almost to the exclusion of gangue material, but in general metallization is moderate. Few bonanzas have been found in these deposits, although many of the ores are of substantial grade. The ore of these veins has commonly become base within 100 feet of the surface and at the same time extraction by amalgamation has fallen from 90 per cent or more to 40 or 50 per cent. Considerable evidence (see pp. 62-63) favors the belief that these veins are genetically related to the great granitic intrusion.

Lead-silver deposits are recognized only in the southeastern part of the county. They are inclosed in Paleozoic formations and are thought to be genetically related to the quartz diorite facies of the granite intrusion. The deposits are irregular tabular bodies with extensions along bedding and joint planes. At the Leadville mine the ore is argentiferous galena remarkably free from gangue; elsewhere it is a mass of earthy lead carbonate heavily stained with iron and manganese. Probably 80 per cent of the lead ore mined in Lemhi County is the product of the oxidation and carbonation of galena, pyrite, and zinc blende. The ore is remarkable for its even tenor, averaging about 35 per cent of lead and 15 ounces of silver to the ton. The deposits are large and show every evidence of continuity. In most of the mines about 200 feet of oxidized ore remains between the deepest workings and the water level, below which primary ore may be expected. It is a matter of considerable importance to know in what respects the primary ore will differ from that now being mined. Studies of the volume changes involved in the oxidation and carbonation of galena, sphalerite, and pyrite lead to the conclusion that leaching has been important in the oxidized zone. From a consideration of the relative solubility of the oxidation products it appears that lead has remained essentially stable, that iron has probably been removed somewhat, and that zinc has been removed in considerable quantities. It follows, therefore, that below the zone of oxidation lead will decrease appreciably in amount per ton of ore, iron will increase somewhat, and zinc will probably increase considerably.

The copper deposits of the county have not proved of great commercial importance. They include fissure veins, impregnations along shear zones in schist, and contact-metamorphic deposits, with irregular mineralization along sheeted zones as the most common type. The characteristic ore is coarse quartz, studded and stained with the alteration products of chalcopyrite and carrying a little free gold. In many respects these deposits are similar to the older pyritiferous gold veins, with which they are thought to agree in age and genesis.

Cobalt-nickel deposits are confined to the Blackbird district, where they occur as lenslike bodies and as bunches and disseminations along fractured zones. In one place nickeliferous pyrrhotite occurs as small

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bunches scattered through a gabbro dike. The deposits are little developed, but some of them are known to contain about 2 per cent each of cobalt and nickel.

Tungsten is mined in the Blue Wing district, where it is associated with zinc, copper, lead, molybdenum, iron, and silver minerals in lenticular quartz veins. A little gold also is present. The characteristic tungsten mineral is hübnerite.

Sixty-three mineral species are recognized in the ores of Lemhi County.

The outlook for a steady growth in the mining industry of the county is bright. A large tonnage of base gold ore remains. Placers are now being worked by dredges, which are converting into an asset ground heretofore valueless for mineral. The annual production of lead-silver has increased greatly since the advent of the railroad and seems destined to become the most important in the county. Tungsten will probably become an asset, but the future of cobalt and nickel is more uncertain.

GEOLOGY AND ORE DEPOSITS OF LEMHI COUNTY. IDAHO.

By JOSEPH B. UMPLEBY.

INTRODUCTION.

SCOPE OF REPORT.

The present report embodies the results of reconnaissance studies in the nineteen mining districts of Lemhi County, Idaho. The necessity of covering approximately 3,200 square miles during a single field season obviously involves a lack of balance in the observations on particular localities. Doubtless some areas and mines were slighted and others received more attention than their relative merits warrant. During the season, however, all the mines and most of the prospects were visited; a topographic and geologic sketch map was prepared (see Pl. I); notes were taken on the general geology; and a persistent effort was made to give ample time to significant points even at the expense of other work.

In the following pages the geography and history, physiography, general geology, and economic geology of the county as a whole are discussed, and afterward descriptions are given of the several mining districts, with notes on the mines of each. Thus the general reader can confine his attention to the first part of the bulletin, but he who is interested in a particular area should turn to the descriptions of individual districts.

FIELD WORK AND ACKNOWLEDGMENTS.

Field work began June 30, 1910, and continued until October 2 of the same year. Extensive development during the following winter in the lead-silver deposits made it advisable to revisit the southeastern part of the area for two weeks during 1911. At this time Mr. George H. Girty, of the Geological Survey, spent three days in company with the writer in collecting fossils and studying the Paleozoic stratigraphy about Gilmore.

Courtesies extended by the many mining men of the county are too numerous for separate mention but were highly appreciated and facilitated the studies materially. It would be unappreciative, however, not to thank Mr. Allen C. Merritt for the opportunity of using his map of Lemhi County; Mr. J. H. Bacon, chief engineer of the Gilmore & Pittsburgh Railroad, for access to surveys, profiles, and

route map; and the engineering firm of McClung & Crandall for additional control in the Lemhi Valley. It is also desired to express special appreciation to Mr. M. M. Johnson, consulting engineer for the Pittsburg-Idaho Co. and Allie Mining Co., and to Mr. Ralph Nichols, president of the Latest Out Co., for hastening certain mine surveys in order that they might be available for this report.

EARLY WORK.

Prior to the present investigation little had been recorded concerning the topography, geology, or ore deposits of the 3,200 square miles treated in this report. The principal map of the county is that by Allen C. Merritt. The route map of the Gilmore & Pittsburgh Railroad is more accurate for the Lemhi Valley, however, and certain Forest Service maps portray more closely the area west of Salmon. For several of the mining districts claim sheets are available, and a railroad survey extends from Salmon both up and down Salmon River. In addition to these sources of control, the writer drew from the field sheets of W. H. Barringer, who mapped Salmon River below Salmon for the United States Geological Survey. Further, the Carpenter survey of the International Boundary, and numerous township plats by the General Land Office were available. Plate I (in pocket) is compiled from these several sources and from numerous aneroid readings and triangulations by the writer.

In 1895 the Geological Survey published a report by George H. Eldridge on his reconnaissance across Idaho, which included a traverse from Yellow Jacket to Salmon and thence south along Salmon River. Other than this only a few articles in technical journals and notes in the reports of the State mine inspector deal with the geology and mineral deposits of Lemhi County.

Following is a list of the more important articles and publications on this and near-by areas.

EMMONS, S. F., Livingston to the Snake Plains: *Compt. rend. Cong. géol. internat.*, 5th sess., 1893, pp. 367-374. Describes the geology along the route of travel and the geologic history of the Snake Plains.

STONE, GEORGE H., An extinct glacier of the Salmon River Range: *Am. Geologist*, vol. 11, 1893, pp. 406-409. Describes the glacial geology of the Leesburg basin and the mountains west of Salmon.

ELDRIDGE, GEORGE H., A geological reconnaissance across Idaho: *Sixteenth Ann. Rept. U. S. Geol. Survey*, pt. 2, 1895, pp. 211-276. Describes the topography and geology along a route from Boise to Salmon and thence south to Hailey and west to Boise. The report includes notes on the ore deposits at Yellow Jacket and the placers of the Leesburg basin and Kirtley Creek.

GOODE, R. U., Bitterroot Forest Reserve: *Nat. Geog. Mag.*, vol. 9, 1898, pp. 387-400. Contains general description of the reserve and definition of mountain systems.

LINDGREN, WALDEMAR, The gold and silver veins of Silver City, De Lamar, and other mining districts of Idaho: *Twentieth Ann. Rept. U. S. Geol. Survey*, pt. 3, 1900, pp. 75-256. Describes the character and occurrence of the igneous and sedimentary

rocks and the occurrence and nature of the ore deposits of a large area lying south and west of Lemhi County.

BELL, ROBERT, An outline of Idaho geology and of the principal ore deposits of Lemhi and Custer counties, Idaho: Proc. Internat. Min. Cong., 4th sess., 1901, pp. 64-80. Describes briefly the principal mines of Lemhi and Custer counties, stating the amount of development, production, and something of the geologic relations.

RUSSELL, ISRAEL C., Geology and water resources of the Snake River Plains of Idaho: Bull. U. S. Geol. Survey No. 199, 1902, 192 pp. Describes the topography, the basement series of rocks, recent eruptives, lacustrine deposits, and resources of the area.

LINDGREN, WALDEMAR, A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: Prof. Paper U. S. Geol. Survey No. 27, 1904, 123 pp. Describes the topography and the character, occurrence, and geologic relations of the igneous and sedimentary rocks, the structure of the area, and the character, occurrence, and development of its mineral deposits. The Gibbonsville and Mineral Hill districts, Lemhi County, are described briefly.

CARR, HENRY C., Vein structure in the Monument mine: Min. and Sci. Press, vol. 98, 1909, pp. 557-558. Includes notes on the geology and character and occurrence of the ores at Meyers Cove (Singiser), Lemhi County, Idaho.

GEOGRAPHY.

SITUATION AND ACCESS.

Lemhi County, Idaho (fig. 1), situated in the east-central part of the State, lies along the eastern border of that broad area which proved impassable to the Lewis and Clark expedition. In August, 1805, Capt. William Clark crossed the main divide at Bannock Pass and proceeded down Lemhi and Salmon rivers nearly to the place where Shoup now stands. Beyond this point the narrow canyon and precipitous uplands along Salmon River made progress impossible. At this time Salmon River was named Lewis River, after the great explorer and head of the expedition, and it is to be regretted that the name was not retained, especially as another stream in the State is called Salmon River.

At present all important lines of traffic extend eastward, although feasible routes to the west have been located. The most practicable of these seems to be that followed by the recent railroad survey down the deep, narrow canyon of Salmon River to Lewiston. This route has a water grade from Bannock Pass on the east down Lemhi, Salmon, Snake, and Columbia rivers to salt water. The Gilmore & Pittsburgh Railroad, popularly supposed to be a link in a transcontinental line, was completed in 1910 between Salmon, Idaho, and Armstead, Mont., the latter being a point on the Oregon Short Line 90 miles south of Butte. From Leadore, Idaho, a branch extends 20 miles south to Gilmore. Stage routes lead from Salmon, the county seat (see Pl. II, *B*), a city of possibly 1,500 inhabitants, south to Challis and west and north to several mining camps and settlements.

18 GEOLOGY AND ORE DEPOSITS OF LEMHI COUNTY, IDAHO.

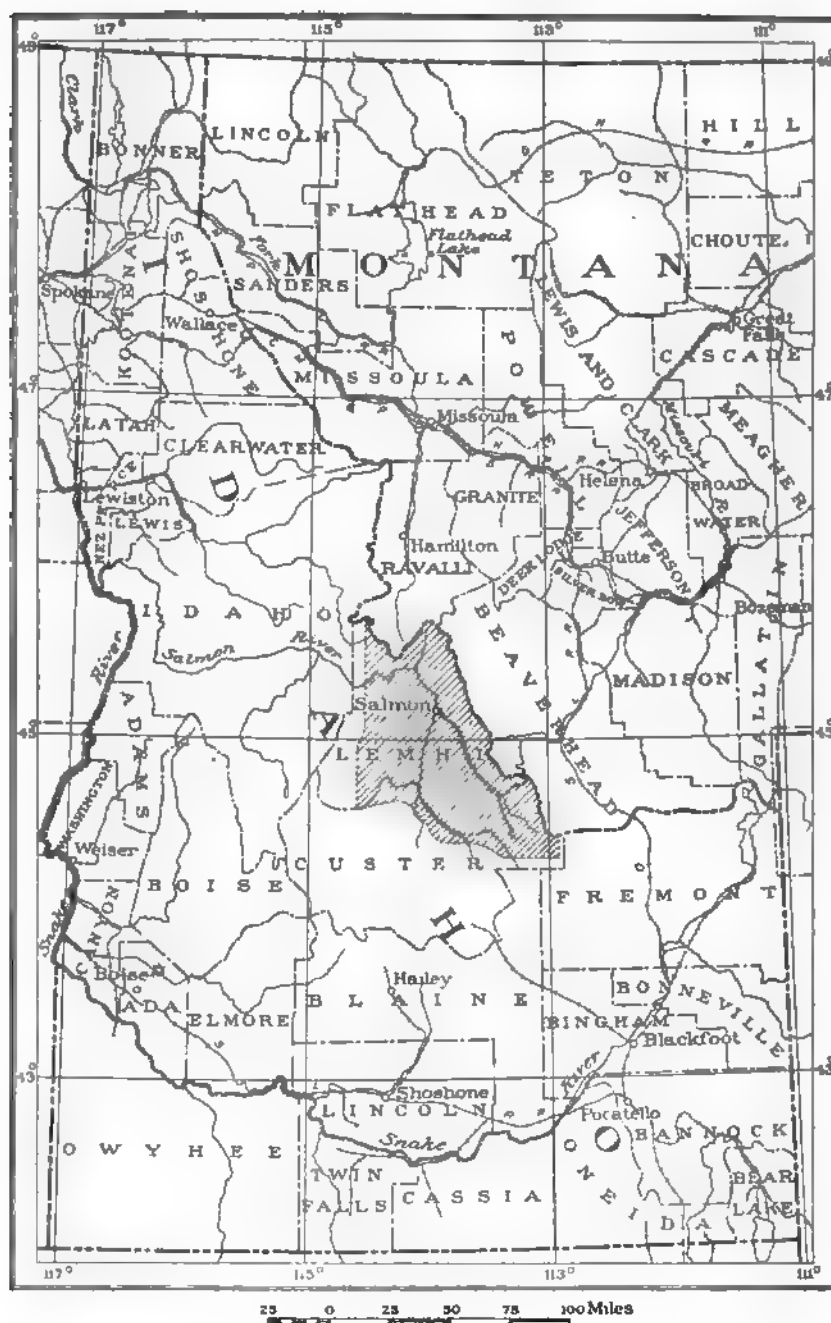


FIGURE 1.—Index map showing location of Lemhi County, Idaho.



1. SALMON CANYON BELOW SHOUP



2. SALMON CITY

Bearhead Mountains in the distance.

CLIMATE, VEGETATION, AND ANIMAL LIFE.

Coordinate with Lemhi County's great range in elevation is its great range in climatic conditions. Expanses covered with snow to a depth of several feet throughout a long winter grade down to lowlands where sleighing is seldom possible. While travelers in the mountains are using skees those in the deeper valleys may be complaining of dust. Unlike many parts of the Northwest, the area is one of abundant precipitation. Almost every mountain canyon is occupied by a stream that lives throughout the year, affording power for the industrialist, fish for the sportsman, and beauty for the traveler.

Over much of the county a dense growth of medium-sized evergreen trees rises above a surface clad thickly with grasses and small shrubs. This growth extends from the lowest valleys to the highest summits, but though thus independent of elevation, it is not uniformly distributed. The great areas of Miocene lake beds are notably lacking in trees, as are also numerous talus slopes adjacent to rugged quartzite summits. The absence of forests on the talus slopes is obviously due to the constant shifting of the surface material, but its absence on the lake beds is less readily explained. Here, however, sagebrush and the grasses of semiarid regions abound, clearly indicating a dearth of moisture, thought to be due to imperfect cementation in the detrital material forming the beds.

The forest trees available for economic use are the yellow pine (*Pinus ponderosa* Lawson), the Douglas fir (*Pseudotsuga taxifolia* Britt), the lodgepole pine (*Pinus contorta* Loudon), and the Englemann spruce (*Picea englemanni* Englemann).¹ Of these the yellow pine has the widest distribution and supplies the only first-class lumber produced in the county. It is the predominant type in the northern and western parts of the area, where "it forms pure stands on south slopes, tops of ridges, and all dry situations." The average tree is about 30 inches in diameter and 120 feet high. Next in importance is Douglas fir, which yields only rough lumber, ties, poles, and fencing, although producing the best quality of fuel wood. It generally grows in open scrubby stands on north slopes and in moist places up to 8,000 feet elevation. The trees are somewhat smaller than the yellow pine. Lodgepole pine, although a small tree, commonly about a foot in diameter, is important because of its wide distribution and great range of uses. It grows on the higher areas throughout most of the county. The Englemann spruce has a wide range in altitude, but is confined to moist canyons and creek beds and is commonly in too small stands to be of commercial importance.

In few parts of the West not included in a game reserve is large game so abundant as in central Idaho, the inhabitants of the forest having

¹ McLean, F. T., Silvical report of Salmon National Forest for 1910, unpublished, but typewritten copy in files of the Bureau of Forestry.

been more or less effectively preserved by the comparative inaccessibility of the region. Within a few hours' travel from any of the mining camps west of Salmon it is possible to kill a deer. Goats and sheep are less numerous, but many are killed each season, and numbers of bear, wolves, coyotes, mountain lions, and, less commonly, lynx annually fall victims to the hunter or are ensnared by the trapper. Antelope and elk have become rare, and the State is endeavoring to revive them by absolute protection, instead of the limited protection afforded to most of the other species.

MINING.

GENERAL CONDITIONS.

Of the many conditions affecting mining, only the lack of suitable means of transportation has served as a serious handicap to development. Prior to the spring of 1910 Red Rock, Mont., and Dubois, Idaho, were the nearest railroad points, and these represented a haul of more than 70 miles from the properties situated advantageously and of more than double that distance from other mines. Even now, with the railroad terminus at Salmon, the western and northern parts of the county are benefited but little so far as marketing ore is concerned. Except the lead-silver deposits the ores are not of sufficiently high grade to warrant a long wagon haul. If transportation charges were made reasonable, however, it is almost certain that several properties in the eastern and northern parts of the county would become substantial producers.

The climate is in no sense prohibitory to successful and cheap mining, timber is abundant, and water power is practically unlimited. Deep valleys adjacent to most of the deposits make it possible to attain 1,000 to 2,000 feet of depth without recourse to deep shafts.

HISTORY.

Lemhi County, like most of the Rocky Mountain mining districts, owes the discovery of its mineral wealth to the great army of gold seekers that invaded the Sierra of California about the middle of the last century and thence penetrated to all the mountain areas of the West. Mining history attests the thoroughness of their search, for no important placers have been discovered since, and most of the lode deposits since worked were known to them. In 1862 a group of these men, following the constantly shifting centers of excitement, went to Florence, Mont., thence to Alder Gulch, and then to Elk Creek, where in the spring of 1866 a party of five outfitted and started into the then unknown area of Lemhi County. Nate Smith led the expedition, which included Lydge Mulkey, F. B. Sharkey, William Smith, and Caleb Davis. Only F. B. Sharkey, a resident of Sunfield,

Idaho, survives. Their first location was on Napias Creek, in the north-central part of the county, a short distance above the mouth of Wards Creek gulch. Leesburg, for some years a prosperous camp, sprang into existence near by, and across the road from it Grantsville thrived for a time, each named by Civil War veterans. Starting in several directions from Leesburg, prospectors soon discovered the placers of Moose Creek, Gibbonsville, Bohannon Bar, and Yellow Jacket, the first lode deposit being located at Yellow Jacket in September, 1868. Most of the gold veins which have since become important were discovered during the next 15 years. Lead-silver was discovered in 1880 at Nicholia, copper in 1883 at Copper Queen mine, cobalt-nickel in 1901 at Blackbird, and tungsten in 1903 at Ima.

During the early years of mining in Lemhi County supplies were freighted from Fort Benton, Mont., and later from Corinne, Utah. Not until 1882, when the railroad reached Red Rock, Mont., was the necessary wagon haul less than 250 miles; from that year until 1910 it was about 100 miles. The extension of the railroad to Salmon has produced a substantial increase in mining in the territory along its route, the activity being especially marked by the lead-silver production of the last year, by recent activity at the Copper Queen mine, and by the installation of a large dredge on Kirtly Creek, which will increase the copper and gold output for the county. In the region west and north of Salmon the railroad has not proved to be of great benefit, for the wagon haul is still so long as to prohibit the shipment of the common grade of ores.

PRODUCTION.

The total production of Lemhi County to January, 1911, is estimated at \$20,000,000. Official records are available for the period from 1881 to 1910, but the important placer operations were carried on before 1881 and little reliable information concerning them is to be had. At that time many individuals worked many properties, gold dust was used instead of money, and gambling was rife. Long-time residents of the county place the early placer production at \$7,000,000 to \$30,000,000, but the area of ground worked, the reported richness, and the known production since 1880, lead the writer to the opinion that \$6,000,000 is probably a fair estimate for the period prior to 1881. From 1881 to 1910, inclusive, the production included \$7,702,256 from gold, \$1,862,081 from silver, \$32,563 from copper, and \$3,822,270¹ from lead. The figures for 1911 show a marked increase in the amount of lead and silver, and a new metal, tungsten, was added to the list.

¹ About \$1,500,000 of this amount is based on estimates. See pp. 84, 91.

Considered by districts, Mackinaw has been the chief source of gold, producing about \$6,250,000. The Gibbonsville district is next in importance, with about \$2,000,000, and then follow the Mineral Hill, the Indian Creek, and the Yellow Jacket, all of these districts being in the western and northern part of the county. In the production of lead-silver the Nicholia district led with an output of \$2,500,000 up to the close of 1910, but the Texas district, with an equal production at the close of 1911, was probably ahead at the end of 1912. The Junction and Spring Mountain districts, each with an output of approximately \$100,000, constitute the remaining lead-silver districts, all of which are situated in the southeast part of the county. Copper has been derived almost exclusively from the Copper Queen mine, in the McDevitt district.

The production of Lemhi County for the years 1904 to 1911, inclusive, as published annually by the United States Geological Survey in Mineral Resources of the United States, is as follows:

Mine production of gold, silver, and associated metals in Lemhi County, Idaho, in 1904-1911, inclusive.

Year.	Gold.		Silver.		Copper.		Lead.	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
DEEP MINES.	<i>Fine ounces.</i>		<i>Fine ounces.</i>		<i>Pounds.</i>		<i>Pounds.</i>	
1904.....	9,952	\$205,726	44,168	\$25,286	5,000	\$625	1,827,400	\$79,949
1905.....	3,309	68,403	38,930	23,517	.....	.....	1,796,000	84,412
1906.....	3,777 51	78,088	36,324	24,337	40,000	7,720	1,144,000	68,208
1907.....	2,502 83	51,738	50,444	33,263	52,461	10,492	1,932,356	102,415
1908.....	1,785 13	36,902	22,825	12,088	10,364	1,368	700,622	29,420
1909.....	5,115 17	105,740	5,564	2,893	46,240	6,012	132,071	5,679
1910.....	2,456 26	50,982	150,119	81,064	54,887	6,971	6,520,474	267,165
1911.....	4,240 84	87,066	332,904	202,959	390,600	48,832	16,854,922	758,471
PLACERS.								
1904.....	2,236	46,222	397	176	.....	.....	.....	.....
1905.....	1,440	29,768	421	255	.....	.....	.....	.....
1906.....	1,346 08	27,944	128	87	.....	.....	.....	.....
1907.....	1,570 93	32,474	128	84	.....	.....	.....	.....
1908.....	1,730 83	35,780	167	88	.....	.....	.....	.....
1909.....	1,164 29	24,058	111	58	.....	.....	.....	.....
1910.....	772 98	15,979	66	30	.....	.....	.....	.....
1911.....	1,621 68	33,523	135	72	.....	.....	.....	.....
		930,903		406,265		82 020		1,442 725

PHYSIOGRAPHY.

EXISTING TOPOGRAPHY.

Lemhi County is a high mountainous area consisting of broad, level-topped divides, generally separating deep narrow valleys. The Continental Divide, which forms the north and east boundaries of the area, is the summit of a high, narrow range, which from the scanty evidence available seems to be largely, if not entirely, a product of erosion. In the vicinity of Shoup the headwaters of Bitterroot

River have crowded the crest line several miles to the south, and above Gibbonsville North Fork of Salmon River, acting in the opposite direction, has crowded it sharply north, thus forming an S, conspicuous on any map of the State boundary.

The divide is known to continue southeast without an important break to Beaver Canyon, where the Oregon Short Line Railroad crosses it. Northward the range splits, the eastern part continuing as the Continental Divide and the western part as the Bitterroot Mountains. For this section of the Continental Divide, between the Bitterroot Mountains and Beaver Canyon, the name Beaverhead Mountains is here proposed. The name is suggested by Beaverhead County, Mont., which comprises a considerable part of the divide; Beaverhead River, which drains much of its eastern slope; and Beaverhead National Forest, which is coextensive with a greater part of it.

West and south of Salmon River the mountains are carved from a high plateau made up of rocks of diverse composition. The same type of topography is seen in the Lemhi Range, although there the dissection is further advanced.

Of the several valleys that of Salmon River is the most important, though smaller than some of the others. (See Pl. II, A, p. 18.) Near the mouth of Pahsimeroi Valley, at the southern boundary of the county, the river enters a deep, narrow canyon which continues to a point within 8 miles of Salmon, where it opens out into a broad intermontane depression. This depression continues downstream for 20 miles and then merges into a canyon even narrower and more rugged than the first. The Lemhi Valley, in contrast to this erratic topographic feature, is broad and open, bordered by precipitous walls which gradually diverge headward and continue beyond an imperceptible divide, as the sides of Birch Creek valley. The Pahsimeroi Valley is similarly a wide depression and is occupied by an even smaller stream.

PHYSIOGRAPHIC DEVELOPMENT.

General features.—Throughout the area there is striking accordance in the elevation of interstream tracts, which, when seen from slight prominences above their level, present the semblance of a broad plain extending southeast, southwest, and north to the horizon. Eastward the Beaverhead Mountains, which in their northern part stand a little above the general level, cut off the view. From such a vantage point an observer would scarcely suspect the area to be furrowed by narrow valleys in places to depths of 5,000 feet. Significant details of contour are the spurs which extend from the main divides and terminate in square shoulders along the major valleys, features which are not to be explained by structure but point to the

dissection of a once nearly level surface. Also significant are certain rock-cut terraces which parallel the plateau surface at slightly lower levels. One of these is on the west side of the Lemhi Range at Spring Mountain.

The surface rocks are gneiss, granite, and sharply folded schists, slates, quartzites, limestones, and dolomites, yet the plateau surface extends across all these rocks, truncating the resistant and nonresistant alike. This uniform truncation of upturned strata over broad areas can have resulted only from profound erosion, which during its later stages operated at elevations where differences in rock resistance no longer produced noticeable differences in surface contour. It is concluded, therefore, that the surface of this area has been reduced to one of gentle contours and since elevated. (See figs. 2 to 4.)



FIGURE 2. — Looking toward surface and lower part of plateau from a point, nearly west of Gilmore, Idaho. The rocks are chiefly folded schists and slates of Tertiary age. (Drawn from photograph.)

Erosion surface. Were the flat-topped divides of the area used to determine a plane it would be found to record minor flexures, some faulting, and a broad anticline extending east and west through the Texas district. Such a plane however would probably prove much more nearly level than the structure of the Miocene lake beds (see p. 38) would indicate. The broad east and west anticline above referred to is post Miocene, for it involves a gradual increase in the elevation of the lake shore that follows the Lemhi Valley and of the mountain crests from Salmon southeast to Gilmore. Near Gilmore the summits stand at about 10,500 feet, but about Salmon they are commonly at 8,500 feet, which is about the normal elevation of the summits throughout the region.

Correlation.—It is not proposed in the present paper to enter on the broad physiographic problem, but in order to date this surface of erosion it is necessary to form some idea of its extent. The same surface has been observed by Lindgren¹ in the Clearwater Mountains and in west-central Idaho; by Calkins² in the Coeur d'Alene, Cabinet, and Purcell ranges; and what is probably the same surface by Willis³ in the Lewis, Livingston, and Galton ranges, Mont., by the writer⁴ at Republic, Wash., and by Dawson⁵ in the Interior Plateau of Canada.

Throughout this broad area the surface of recognized similarity varies in elevation from 4,500 feet to 10,500 feet, although elevations of 6,000 to 7,000 feet are the more common. In Canada and eastern

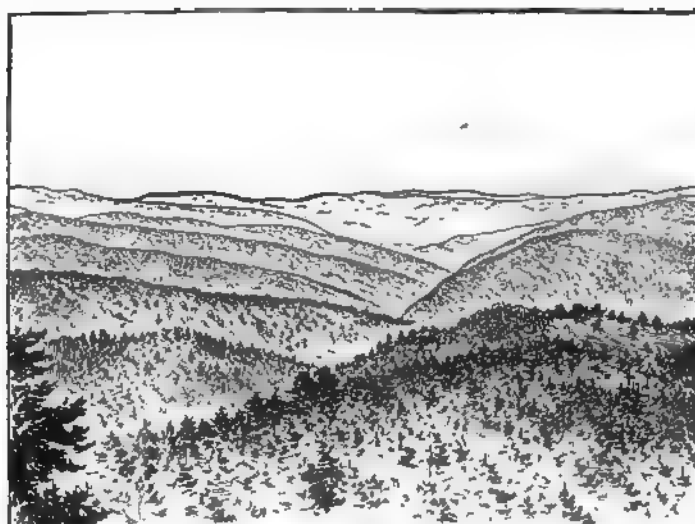


FIGURE 3.—Eocene erosion surface northeastward from Gibbonsville. Some of the valleys are 4,000 feet deep. Drawn from photograph.

Washington the surface has been recognized as Eocene and assigned to the same epoch as that in Lemhi County, which in turn is continuous with the west-central Idaho and Clearwater Mountain areas. The other localities mentioned above presumably present the same surface, a deduction resulting from considerations outlined in the next section.

¹ Lindgren, Waldemar, The gold and silver veins of Silver City, De Lamar, and other mining districts of Idaho: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, p. 77; A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: Prof. Paper U. S. Geol. Survey No. 27, 1904, pp. 13-14.

² Calkins, F. C., and MacDonald, D. F., A geological reconnaissance in northern Idaho and northwestern Montana: Bull. U. S. Geol. Survey No. 384, 1909, pp. 14, 16.

³ Willis, Bailey, Stratigraphy and structure, Lewis and Livingston ranges, Mont.: Bull. Geol. Soc. America, vol. 13, 1901, p. 349.

⁴ Umpleby, J. B., Geology and ore deposits of Republic mining district: Bull. Washington Geol. Survey No. 1, 1909, p. 11.

⁵ Dawson, G. M., The physiographical geology of the Rocky Mountain region in Canada: Trans. Roy. Soc. Canada, 1900, p. 13.

Age of the surface.—Sediments assigned to the Miocene on fossil evidence occupy a broad erosion valley developed after the area had assumed its present elevation. (See p. 36.) Obviously, the old erosion surface is pre-Miocene.

Vast volumes of sediments must have resulted from the reduction to a gentle topographic feature of the broad area known to have been eroded, and herein lies the possibility of further defining its age. The surface cuts Carboniferous beds, and as it is pre-Miocene only Mesozoic and early Tertiary deposits need be considered. Post-Paleozoic formations in the Northwest earlier than those of late Cretaceous time seem to bear no genetic relation to the plateau region as a whole. The Triassic sea occupied part of the same area, and Jurassic



FIGURE 4.—Eocene erosion surface southward from Copper King Mountain. Out across granite, quartzite, slates, and schists. Drawn from photograph.

deposition occurred a little farther east. The late Cretaceous is strongly developed in the adjoining areas to the east and much of the material was presumably derived from highlands to the west. The distribution of Eocene sediments, however, is far more suggestive. (See fig. 5.) They surround the plateau area in such a manner that their derivation from it, at least in large part, seems obvious. The great volume of these deposits could not have resulted from the plateau region after its last elevation, for two reasons. (1) It is very doubtful if the plateau is sufficiently dissected to afford the volume of material represented by the Eocene beds, and (2) all the great valleys which developed after the last great elevation drained westward and in all probability have done so throughout their history. This is true of the Rocky Mountain trough, the Purcell trough, and

the Snake, Salmon, and Columbia River channels. It seems, therefore, only possible that the extensive Eocene deposits on the east could have been derived from the plateau region during that period of erosion which resulted in its reduction well toward base-level. Whether or not that great cycle of erosion began with the Eocene may be an open question, but that it closed with the Eocene, and therefore that the surface is of Eocene age, seems practically beyond doubt.

The Eocene sediments of the Northwest record four more or less distinct stages. This may mean either that the area supplying the material was affected by successive uplifts or that slight warpings or perhaps only piracy caused the courses of the principal streams to change from time to time. The latter view is the more probable, for beds representing successive stages in the Eocene epoch for the most part occupy different areas.

Early Eocene elevation.—A comparison of figures 5 and 6 brings out the remarkable accordance in the extent of the plateau area and in the distribution of granitic rock which may reasonably be assigned to the late Cretaceous or early Eocene age. Many of the granitic areas are shown definitely to be portions of the same batholith, but the age of others has not been determined. The magnitude of the masses which entered at about the same time, however, is almost inconceivable. It does not seem possible that such a volume of molten rock could enter the outer zone of the earth without being accompanied by a profound elevation of the surface; yet nowhere is there a record of such elevation until Eocene time. The Triassic and Jurassic seas probably crossed parts of the area now occupied by the granite, and within the configuration of the Cretaceous shore line, as commonly defined, there are no features indicating a pronounced highland centering in Idaho. Thus, prior to the Eocene, there is no evidence of special elevation in the area now common to granitic outcrops and the old erosion surface.

From these lines of evidence it is concluded that the probability is strong that the intrusion of the granite accompanied the broad elevation which was reduced to gentle topographic forms during the Eocene epoch; and therefore that the great granite mass which attains its greatest development in Idaho is of late Cretaceous or early Eocene age.

Bearing of Eocene erosion surface on economic problems.—Over much of the plateau region no geologic datum plane is recognized between the Algonkian and the Pleistocene. All the ore deposits and associated igneous activity were well removed in time from both of these periods, and hence the economic geologist is frequently at a loss to date his deposits. The Eocene erosion surface, however, constitutes a widely recognizable datum plane, separating two great periods of mineralization. As the older deposits are later than ~~them~~

granite, the age of the granite is important, and if the above suggestion of a genetic relation between it and the Eocene surface can be established, the numerous pre-Oligocene ore deposits found in

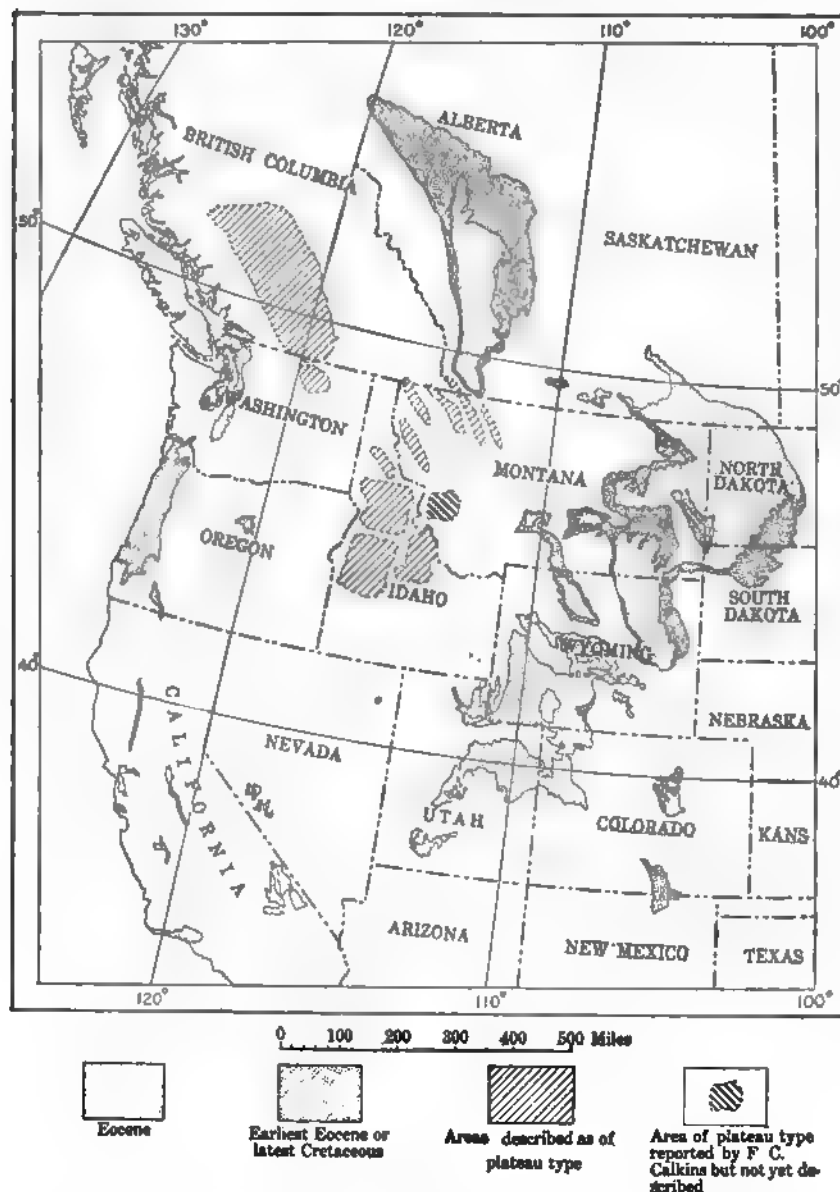


FIGURE 5.—Map showing distribution of Eocene deposits in the Northwest. Adapted from geologic map of North America.

Idaho are confined to the late Cretaceous or early Eocene. The later deposits are inclosed in or associated with eruptive rocks, which occupy valleys developed after the elevation of the Eocene surface.

If the Oligocene epoch is allowed for the development of these valleys the later deposits are post-Oligocene. They are further limited in age by Pleistocene glaciation and by the amount of erosion which preceded the glaciation but followed the development of the veins. Thus the later period of mineralization is Miocene or early Pliocene.

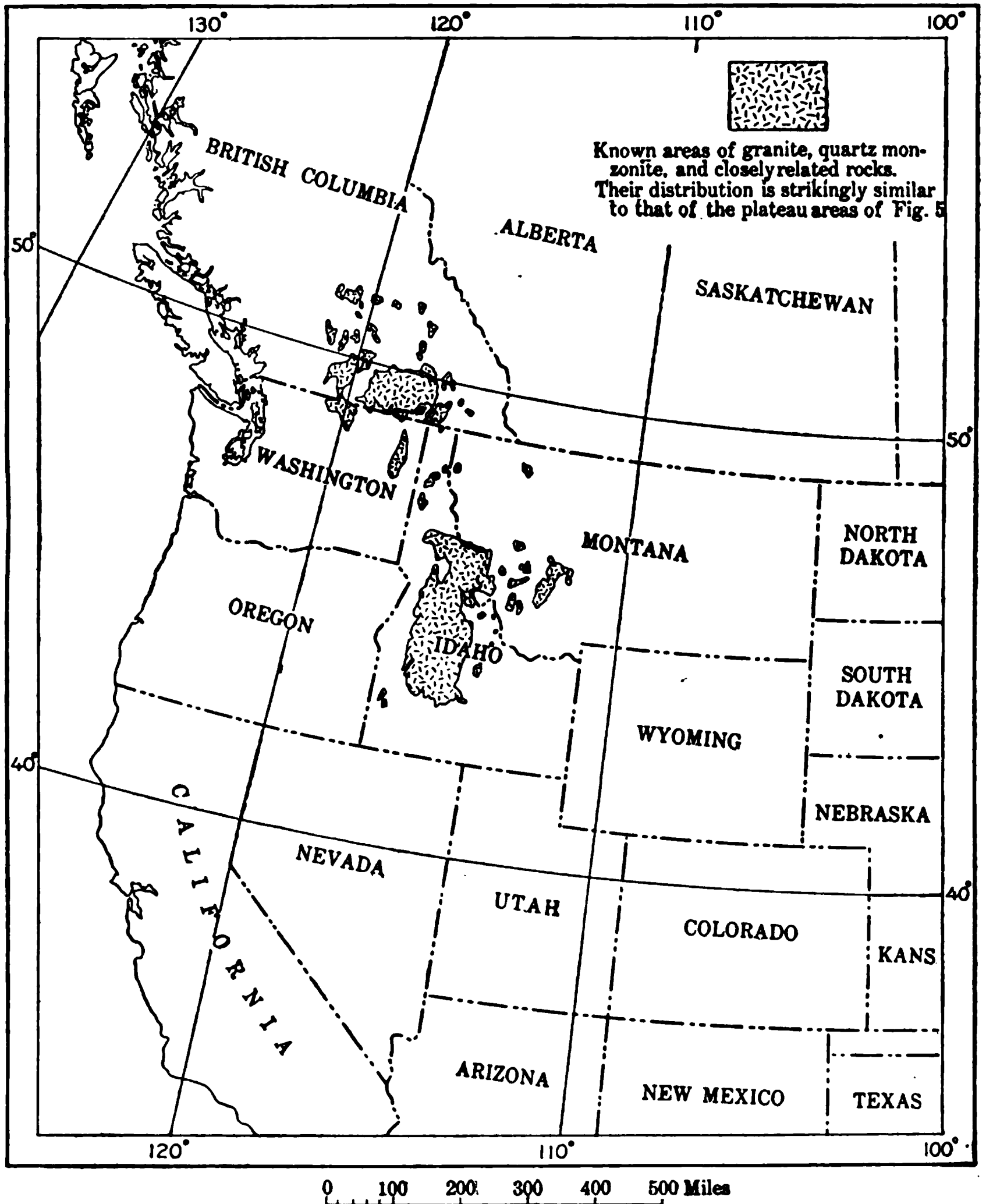


FIGURE 6.—Map showing distribution of outcrops of granitic rocks in the Northwest. These are strikingly coincident in distribution with the plateau area. Adapted from geologic map of North America.

POST-EOCENE TOPOGRAPHY.

The post-Eocene geography of the area has changed greatly from stage to stage. The marked discordance in degree of development of the valley of Salmon River from place to place, and in the Lemhi

and Pahsimeroi valleys with reference to it, has been indicated (p. 23). It has also been pointed out that the Lemhi Valley increases in width toward the head of its stream and beyond, and that many of its tributaries run headward until they reach the valley flat, where they assume a normal inclination downstream. Prairie Basin is a high rolling tract, isolated by a broad area of Tertiary lavas, which may conceal a former connection with the Pahsimeroi Valley.

All the above-mentioned features are independent of structure and point clearly to profound drainage changes. The valleys now partly filled by Miocene sediments were undoubtedly formed by rivers which flowed southward and joined Snake River through the present channels of Birch Creek and possibly Little Lost River. These relations prevailed until erosion began to operate on the lake beds, when the head of the basin was tapped by Salmon River. Since then the drainage has been to the north and west. The explanation of the restricted valley occupied by Salmon River from a few miles above Salmon nearly to the entrance of the Pahsimeroi is not altogether clear but probably is to be explained by headward erosion. The broad valley of the Pahsimeroi, like that of the Lemhi, is thought to have been formed by a southward-flowing stream.

Pleistocene glaciation on all elevations above perhaps 8,000 feet, and along the larger drainage line down to 7,000 and rarely to 6,000 feet, developed deep U-shaped valleys and countless cirques in the higher mountains. (See also p. 40.)

GENERAL GEOLOGY.

AGE AND SUCCESSION OF THE ROCKS.

The rock formations of Lemhi County comprise¹ a basement of Archean gneiss, a widespread unconformable series of intensely metamorphosed schists, slates, and quartzites of Algonkian age, and an unconformable series of Paleozoic formations, which are preserved only in the southeastern part of the county. The Mesozoic is not represented by stratified rocks, but intrusions of granite probably of late Cretaceous or early Eocene age occur at several places in the area, attaining their maximum development west of Leesburg.²

An Eocene erosion surface is recognized on most of the summits at elevations greater than that of the next younger rocks, which are Miocene lake beds and Miocene and Pliocene lavas. Glacial débris covers much of the highland areas and extends down the larger valleys to elevations of 7,000 feet, rarely to 6,000 feet.

SEDIMENTARY ROCKS.

ALGONKIAN SYSTEM.

Algonkian sedimentary rocks are widespread and of great thickness in Lemhi County. Although, owing to the limitations of hasty reconnaissance work, they are here considered a unit, their lithologic varia-



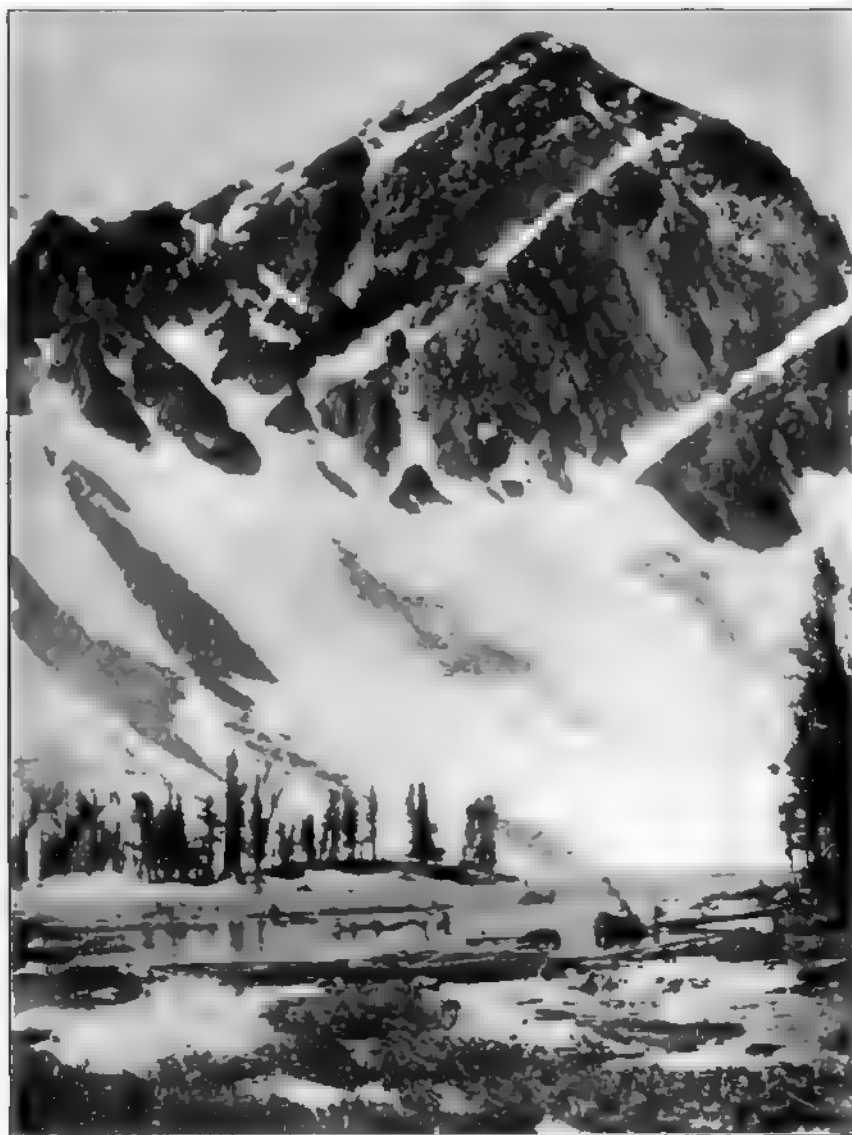
A. EAGLE PEAK.

Portion of quartzite cliff along Salmon River near entrance to canyon.
Photograph by Percy Anderson.



B. HOT SPRING 3 MILES WEST OF COPPER KING MOUNTAIN.

Photograph by Percy Anderson.



CAYHORAN QUARTZITE CLIFF AT HEAD OF MEAD LAKE, COLORADO, TEXAS DISTRICT
S. H. HEDGECOCK, U. S. GEOLOGICAL SURVEY, PHOTOGRAPH

tions are so great that detailed work will be sure to lead to several broad subdivisions. Indeed, at present it is possible to recognize several of the subdivisions of the Algonkian of Montana and Idaho assembled in tabulated form by Calkins.¹

The rugged range that forms the Beaverhead Mountains is carved out of these rocks from Agency Creek northward, and most of the level-topped highlands west of Salmon River are formed by their truncated edges. (See Pl. III, A.) Within their general area they are in places widely concealed by lake beds and lava flows, and elsewhere are displaced by granite and dikes.

The Algonkian sedimentary rocks are uniformly though not intensely metamorphosed. Crumpling or intricate foliation is seldom seen, and in most places bedding structure may be recognized. Yet, in general, crystallization of the constituents has taken place, biotite and sericite being most commonly developed. Some garnet and chiastolite and more amphibole have been formed.

The rocks have had an eventful history, recorded in intricate jointing and extensive shearing. Faulting is indicated by breaks from one type of rock to another along the strike and by changes of attitude within short distances.

The base of the Algonkian as exposed near Shoup is a fine-grained micaceous schist, locally including abundant fragments of the underlying gneiss. It gives way in a short stratigraphic distance to quartzite beds which alternate with those of schist and slate for 200 or 300 feet. About Ulysses, 8 miles northeast of Shoup, the rocks are little different, but around Gibbonsville there is vastly more clayey material, the series being made up of dark thin-bedded slates and subordinate amounts of quartzite, which in many places grades into them. Bedding is fairly well preserved, although jointing is very intricate and metamorphism is well advanced. Biotite, the chief metamorphic mineral, is mostly oriented parallel to the bedding, although in places it conforms to cleavage planes which lie at 45° thereto.

In contrast to these predominant argillites to the north, gray-banded quartzites prevail in the Eureka district and along the Beaverhead Mountains east and northeast of Salmon. In the former locality the quartzite is dark gray, with faint banding resembling fine laminations, but in the latter it is uniformly light gray. In both localities the quartzites are fine grained and compact with rather thick bedding. A quartzite resembling that of the latter locality occurs about the Black Eagle mine in the Yellow Jacket district, although the best exposures of this phase of the series are along the south branch of Carmen Creek, especially in the cirque walls north of Fremont Peak.

¹ Ransome, F. L., and Calkins, F. C., The geology and ore deposits of the Coeur d'Alene district, Idaho: Prof. Paper U. S. Geol. Survey No. 62, 1906, p. 27.

Still another facies of the older rocks occurs in the mountains east of Baker and is well exposed in Pratt Creek canyon, near its mouth. Here a steep cliff, possibly 700 feet high, is formed by thinly bedded horizontal layers of quartzites, argillites, and schists, the individual members ranging in thickness from 1 to 5 feet and being conformable throughout. These beds are distinguished from those before described by their thin bedding and by the veinlets of calcite which occupy some of the joint planes. It is probably this phase which is extensively developed, though poorly exposed, in the southern part of the Yellow Jacket district. The rocks are not known in contact with the Cambrian system, but as they occur in general parallel to and not far from the outcrop of the Cambrian formations it is thought that they are near the top of the Algonkian system.

Detailed correlations can not be based on as incomplete work as the present, but purely as a working hypothesis it might be suggested that the rocks above described correspond to the Prichard slate, Revett quartzite, and Wallace formation of the Cœur d'Alene section.¹ Broadly, there is no doubt that they are to be correlated with the known Algonkian sections of Idaho and Montana.

PALEOZOIC ROCKS.

CAMBRIAN SYSTEM.

Cambrian quartzite outcrops along the crest and east slope of the Lemhi Range, from the vicinity of McDevitt Creek southward beyond the limits of the reconnaissance. The higher peaks of this part of the range, those which rise as high as 10,800 feet above sea level, are carved out of this formation. North of the Lemhi Valley the quartzite continues, crossing the Beaverhead Mountains a little south of Lemhi Pass.

The formation was studied only in the vicinity of Meadow Lake, where it is uniformly a clear-white fine-grained quartzite, more than 2,000 feet in thickness. (See Pl. IV.) A notable feature is the absence of conglomeratic and even of granular facies. Individual grains can not be distinguished with the unaided eye, and fresh surfaces have a rather opalescent appearance. When microscopically examined, the individual grains are seen to be well rounded and to average about 0.3 millimeter in diameter, the largest measured being only 0.5 millimeter. Recrystallization was unimportant in the metamorphism of the original sandstone, the firmer cementation being due to an infiltration of silica into the interstices between the grains rather than to a crystallographic addition to them. The quartzite is remarkably free from mica or other common impurities.

No fossils were obtained from this quartzite. Throughout its known extent the general dip of the formation is about 45° E., al-

¹ Ransome, F. L., and Calkins, F. C., op. cit., pp. 25, 27.

though local variations to the north and south were noted. Below it stratigraphically are the greatly folded and extensively recrystallized Algonkian schists, so that, although an unconformity between the two was not seen, there is abundant ground for believing that one exists. Conformably above the quartzite is the Ordovician dolomitic limestone. (See Pl. IV.) Added to these local relations, the general presence of quartzite at the base of the Cambrian in many localities to the south and east, and its absence in the Ordovician, leads to the conclusion that it is of Cambrian age.

ORDOVICIAN SYSTEM.

The Ordovician is represented by a massive dolomitic limestone which rests conformably above the Cambrian quartzite, and hence outcrops in the Lemhi Range along its eastern margin. As exposed in the steep wall east of Meadow Lake, 2 miles west of Gilmore, the formation is about 500 feet thick and is made up of massive beds separated by poorly defined partings. Fossils are scattered throughout, but near the base and top they are especially abundant.

The formation here considered is assigned to the Ordovician on the basis of fossils collected from the beds. Edwin Kirk, of the United States National Museum, examined two lots of material from these beds. His report is as follows:

From the bottom of 500-foot massive blue limestone outcropping in the east side of Meadow Lake cirque:

<i>Crepidora</i> cf. <i>ampla</i> .	<i>Halysites</i> <i>gracilis</i> .
<i>Stromatoporoid</i> (indeterminable).	<i>Rhynchotrema</i> (probably <i>copax</i>).
<i>Streptelasma</i> <i>rusticum</i> .	<i>Rhynchotrema</i> <i>anticostiensis</i> .
? <i>Calapoecia</i> cf. <i>huronensis</i> .	Poorly preserved gastropod (indeterminable).
<i>Heliolites</i> sp.	<i>Endoceras</i> sp.
<i>Columnaria</i> <i>alveolata</i> .	

From upper part of same massive blue limestone:

<i>Columnaria</i> <i>alveolata</i> (poor).	<i>Halysites</i> <i>gracilis</i> .
<i>Stromatoporoid</i> (indeterminable).	<i>Diphyphyllum</i> sp.

These two lots seem to indicate unquestionably the Richmond age of the beds containing them. They include several species that are found in beds of similar age in New Mexico, Colorado, Utah, and Wyoming.

SILURIAN (?) SYSTEM.

Beds supposed to be of Silurian age rest conformably above the Ordovician dolomitic limestone in the Lemhi Range, but differ from it in being light gray in color. They are about 200 feet thick as exposed in the west wall of the Meadow Lake cirque, the only locality where they were examined. The beds are meagerly fossiliferous near the top.

Concerning the fossil material gathered from these beds, Mr. Kirk says:

The lot is possibly referable to the Silurian, though the material is in a much poorer state of preservation than that constituting the preceding two (Richmond) lots. The single specimen from this locality consists of the external mold in dolomite of some branching coral. It may have been a *Syringopora*. No structure is shown.

DEVONIAN SYSTEM.

The Devonian is an important division in the southeastern part of Lemhi County, both by reason of its thickness and because of the ore deposits included in it at Gilmore. It rests conformably above the Silurian, and the Mississippian is supposed to lie conformably above it. The beds are well exposed along the divide between Liberty and Silver Moon gulches but are so disturbed (Pl. V, A) that accurate measurement of their thickness is impossible. They are also well exposed along the divide between Liberty Gulch and Meadow Lake Gulch and thence east along the north wall of Liberty Gulch. They were studied principally along the latter course.

The rocks consist predominantly of beds from 1 to 20 feet thick, although they include massive beds at two horizons at least—one about 400 feet from the base and the other near the top. Blue and light-gray dolomitic limestone predominate, but there are numerous beds of slate and some of quartzite. In many parts thin laminations are conspicuous. Narrow siliceous bands are numerous in the shale parts, and much of the limestone itself is siliceous. The Devonian as exposed here is at least 2,000 feet thick and, as the position of its contact with the Mississippian was not determined, it may be much thicker.

The exact areal extent of the Devonian within Lemhi County was not determined. Its outcrops are to be expected only east of a line extending from Spring Mountain north to the vicinity of Lemhi Pass.

Two lots of fossils were procured from these beds. Mr. Kirk referred them to E. M. Kindle "as evidently having Devonian affinities." The lot obtained about 200 feet above the base of the formation "contains nothing but indeterminable fragments, though apparently falling with" the other lot. The collection from a stratigraphic horizon approximately 2,000 feet from the base "contains corals hitherto referred by Kindle to the Jefferson limestone (Devonian). The only form well enough preserved for identification is a *Cladopora* which may be called *C. labiosa* with a question."

CARBONIFEROUS SYSTEM.

MISSISSIPPIAN SERIES.

Mississippian beds crop out about the mouth of Long Canyon, in the southeastern corner of the county, and presumably thence southward beyond the limits of the reconnaissance. The point to the



A. DEVONIAN BEDS ALONG DIVIDE BETWEEN SILVER MOON GULCH AND LONG CANYON,
TEXAS DISTRICT



B. TERMINAL MORaine AT MOUTH OF MEADOW LAKE CANYON
Miocene lake beds in background and Beaverhead Mountains in distance.

north where they cross into Montana was not determined. Throughout their known area they dip predominantly to the east. Their contact with the Devonian beds below was not recognized, and, as the known outcrops of the two divisions are perhaps half a mile apart, it is possible to assign only minimum values for the thickness of each. The upper limit of the Mississippian is even more uncertain, for the Miocene lake beds lap over its eroded edges. Thus only a comparatively small part, possibly 300 feet of the section, is known definitely to be of Mississippian age. Here the rocks are made up of massive blue limestone, which at one horizon is rich in fossils.

A suite of fossils was collected near the base of the Lemhi Range, just north of Dry Gulch. George H. Girty has examined the material and his report is given below:

After careful examination of the collection which you and I made in the Carboniferous limestone south of Gilmore, Idaho, I am able to distinguish the following species:

Lithostrotion martini, E. and H.	| Clisiophyllum teres Girty.
Lithostrotion portlocki McCoy.	| Composita sp.
Syringopora surcularia Girty.	| Fenestella sp.

Some of the identifications are more or less doubtful. The fauna belongs in the upper Mississippian coral horizon of Utah and Idaho.

CENOZOIC DEPOSITS.

TERTIARY SYSTEM.

MIocene LAKE BEDS.

Distribution and thickness.—From a point near the mouth of Fourth of July Creek, in the north-central part of the county, southeastward at least 90 miles, and presumably much farther, extends a belt of lacustrine beds averaging about 8 miles in width. Similar deposits occur in a small area in the Moose Creek basin to the west (fig. 7), and others probably lie beneath the wash which mantles the floor of the Pahsimeroi Valley in the south. The Prairie Basin may be another such area, although evidence of this is not satisfactory.

The maximum thickness of these lake beds is not known, but Salmon River in the vicinity of Salmon has cut into them to a depth of 1,800 feet. On Bohannon Bar placer workings have exposed the eroded edges of the beds for about 2 miles, and throughout they show a uniform dip of 20° to 22° E. As a hasty traverse failed to reveal duplication by faulting, it is supposed that about 4,000 feet of beds are present in this exposure.

Great as these measurements are, it is believed that the maximum thickness of the beds is attained only near the head or south end of the Lemhi Valley. The depression in which they were formed evidently drained southward (p. 23) and less post-Miocene erosion has taken place at the head of the valley. To the south, in Custer County, deposits of the same age and of similar origin are present.

Relations and constitution.—The Miocene lake beds occupy the bottoms of deep, narrow valleys, bordered by precipitous walls 2,000 to 5,000 feet high. The origin of these valleys is of particular interest. They may be regarded as possibly due (1) to erosion, (2) to down-faulting, or (3) to down-folding. Of these alternatives, the first, erosion, is believed to have been the dominant factor in their production. The second and third are untenable because certain of the valleys lie athwart the structure axes of the region. Direct observations show that the valleys are very clearly not the product of down-folding, but the down-faulting hypothesis can not be so certainly refuted in this way because of the possibility that the lake beds conceal the faults along the sides of the valleys which they occupy. The sides of Lemhi Valley beneath the lake beds, as exposed to a depth of 600 or 700 feet in places, are undoubtedly irregular surfaces of erosion, but it is conceivable that these are simply modified portions of fault scarps. If, however, the valleys are due to down-faulting they must have been

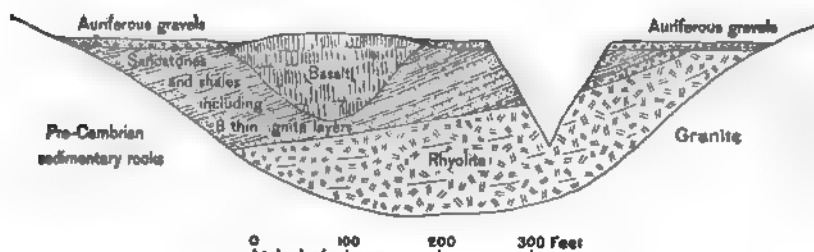


FIGURE 7.—Section at lower end of lake beds, Moose Creek valley. Scale approximate.

blocked out prior to the deposition of the lake beds and after the elevation of the Eocene surface, for the lake which occupied the Lemhi Valley is shown by its shore line to have stood at its maximum 2,800 feet beneath the plateau surface. The elevation to which the lake beds lap up on the older rocks is essentially the same on the narrow and on the wide divides between streams which cross the contact—an accordance which, as the rocks are of diverse resistance to denuding processes, should not prevail if the upper littoral deposits have been greatly eroded at these places. But there is another reason for believing that this is approximately the old shore line. In the vicinity of the divide between Lemhi River and Birch Creek, where even in the central portion of the valley the Miocene deposits are but slightly trenched, the marginal lake beds are essentially the same distance (2,800 feet) beneath the plateau level as at Salmon City, where present streams have cut into them to a depth of 1,800 feet. Thus, even if the valleys are due to faulting it does not invalidate the conclusion concerning the age of the Eocene erosion surface (p. 26). In keeping with their deposition in inclosed basins bordered by precipitous walls, the Miocene deposits vary greatly in composition

and texture, consisting chiefly, in any given place, of fragments of rocks making up the adjacent highlands. As these rocks are largely slates, schists, and quartzites the beds are dominantly shales, siliceous shales, and sandstones. Along the margins and near the north end of the basin, however, heavy conglomerates are locally present, and in the upper part of the lake beds tuffaceous material is abundant. The beds are commonly thinly laminated and vary in color from light gray to buff and maroon.

Four or five lignitic layers, two of which were worked with indifferent success prior to the advent of the railroad, crop out around Salmon and Baker. The lake beds also furnish a commercial building stone from a quarry near Salmon. It is a medium to coarse grained sandstone containing numerous flakes of biotite and some fragments of feldspar. In color it varies from light gray through flesh-pink to intense maroon, which in places grades into reddish yellow.

A detailed section of these Miocene beds was not worked out, but a general idea of their stratigraphic variations may be conveyed by describing exposures between the north limit of the deposits, where their base appears, and the head of Lemhi Valley, their highest exposure.

Eleven miles north of Salmon three massive conglomerate beds aggregating about 125 feet in thickness are exposed along the road for 3 miles. They are made up of subangular waterworn material, most of it measuring less than a foot in diameter but including some boulders 4 or 5 feet across. The cement is silica with some iron oxide. Southward, through transitions not exposed, these conglomerate beds dip beneath thinly bedded sandstones and siliceous shales of buff color. Along the river near Salmon the shales and sandstones continue, but side traverses to the west reveal eastward-dipping beds, with the quarry sandstone conspicuous about halfway up the slope. Farther west intense maroon shales give way to the black shales which inclose the lignite. In the latter locality altered rhyolite, possibly a part of the series, is widely exposed.

Between Salmon and Baker the shaly lignitic bed crops out along the river, and east of it similar beds are exposed in the placers along Bohannon Creek. From Baker southward for 50 miles there are few good exposures although abundant small outcrops prove the continuity of the lake beds. Near Gilmore, however, more than 200 feet of the section appears in some exposures. As seen in the railroad cuts in this vicinity, the beds present chalk-white slopes cut across regularly bedded layers of light bluish-gray fine volcanic ash, in places almost pumiceous enough to float. The bedding is shown by slight changes in color, the individual bands ranging from half an inch to 4 inches in thickness. In places thin layers of pebbles,

consisting of limestone, slate, and quartzite, are interbedded with the tuff, and in other places pebbles and sand are intermixed with it.

These exposures suggest broad changes in the character of the deposits at different stages, from conglomerates at the base through alternating sandstone and shale members to tuffaceous beds at the top. The lignitic beds are interpreted to mean that the lake surface reached its maximum level through a series of stages, for though many of the carbonaceous bands are doubtless drift phenomena, others are thought to represent marsh conditions.

Deformation.—The Miocene lake beds are broadly though not intensely deformed. Both folding and faulting have taken place, but the latter is not general, having been noted in only two places. Near the coal mine west of Salmon a duplication of the coal bed indicates a downthrow on the west of possibly 400 feet. In the Leadville mine, near Junction, a fault with at least 300 feet displacement throws the lake beds against the ore body. Several offsets of a few feet were noted in exposures about Salmon and near Gilmore. Folding has affected the beds, but on the whole they are much more nearly horizontal than the other stratified rocks of the area.

The beds dip in various directions but generally away from north-south axes. About Salmon they incline 20° to 25° E. along both the east and west side of the basin, but toward its center they incline north or south. An east-west syncline, perhaps 100 feet deep, is exposed in the east bank of Salmon River from Salmon almost to Carmen Creek. Above the mouth of Carmen Creek the dip is 20° E. but flattens within a short distance to 10° and near the east limit of the beds is slightly west. One of the most important movements, however, is recorded by the broad east-west anticline which forms the divide between the Lemhi River and Birch Creek drainage basins. The anticline corresponds with the gradual increase in elevation of both the Eocene surface and the shore line of the lake from Salmon to Gilmore, the increase being about 2,000 feet.

Age.—The lake beds occupy broad deep valleys developed in the Eocene surface after its elevation at or near the close of the Eocene epoch. Considerable time must have been required for this excavation, for the streams not only worked headward long distances but they removed vast volumes of material, and it is probably safe to assume that this interval of erosion occupied most of the supposedly short Oligocene epoch. Thus from purely physical relations the beds would probably be assigned to the Miocene or Pliocene, preferably to the former because of the amount of erosion which has taken place in them. Fossil evidence also points to the Miocene. A small suite of material collected 2 miles south of Salmon was examined by F. H. Knowlton, whose report follows:

This collection is small, consisting of about 20 small pieces of matrix, and represents at most only three forms. These are a broad-leaved grasslike monocotyledon,

which is not further determinable, and two forms of conifers, *Sequoia angustifolia* Lesquereux and *Taxodium?* cf. *T. oliviki?* Heer.

Unfortunately neither of these conifers is a very good time marker, for both have a great vertical range. The species first mentioned has been found in the Oligocene, Miocene, and somewhat doubtfully in the Pliocene, but it is more abundant in the Miocene. The other form, if correctly identified, would appear to indicate upper Miocene age. No dicotyledons are present in this collection.

In 1895 I reported on a small lot of material submitted by George H. Eldridge from the vicinity of Salmon, and presumably from a locality near that which afforded the present material—in any event from the same beds. Owing to the confused condition of the collections, caused by moving, I have not been able to review this earlier collection, but I am inclined to think that what was then identified as *Sequoia langsdorfi* is probably the same as that called *S. angustifolia* in the present material. Furthermore, since that report was made additional information has been acquired concerning the vertical distribution of *Glyptostrobus europæus*, which, though common in the Eocene, is not confined to that series. I am therefore inclined to go a step further than at first and to regard these lake beds as Miocene in age. This is not a positive determination, for the material is not sufficiently abundant nor characteristic, but it seems that in all reasonable probability the beds may safely be called Miocene.

Correlation.—It has been shown above that both physical relations and fossils point to the Miocene as the time during which these lake beds were deposited. Correlation with other Miocene formations in the State is therefore feasible, especially with those which have similar physiographic relations. The Payette formation, widely exposed along Snake River between Salmon Falls and Weiser and on to the west in eastern Oregon, was described first as Miocene¹ and later as Eocene.² It is made up of detrital material from the highlands adjacent to the erosion valley in which it was deposited. Tuffaceous material is also conspicuous in parts of the formation. The thickness as recorded by Lindgren is more than 1,000 feet in the vicinity of Boise and the base is not exposed. Locally the strata are inclined as much as 50°, and the old shore line is thought to vary in elevation over broad areas as much as 2,000 feet.³ This opinion is based on exposures near Hailey, which occur at elevations of 6,000 to 6,900 feet, or 2,000 feet higher than the shore line in the vicinity of Boise. It will be noted that the Hailey exposures correspond well in elevation with the upper limit of the lake beds in Lemhi County, and as their character is the same, the two are probably to be correlated. Russell⁴ thought that the Payette formation extends eastward beneath the basalts of Snake River, saying that the known data favor “the hypothesis that beneath the surface lava sheets in

¹ Lindgren, Waldemar, The mining districts of the Idaho Basin and the Boise Ridge, Idaho; with a report on the fossil plants of the Payette formation, by F. H. Knowlton: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, pp. 633, 720 et seq.; The gold and silver veins of Silver City, De Lamar, and other mining districts in Idaho: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, pp. 93–99. Russell, I. C., Geology and water resources of the Snake River Plains of Idaho: Bull. U. S. Geol. Survey No. 199, 1902, pp. 50–58.

² Lindgren, Waldemar, Silver City folio (No. 104), Geol. Atlas U. S., U. S. Geol. Survey, 1904, p. 2; Nampa folio (No. 103), idem, U. S. Geol. Survey, 1904, p. 2.

³ Lindgren, Waldemar, Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, p. 95.

⁴ Op. cit., p. 59.

its eastern part extensive beds of clay, sand, etc., do occur." It is thought that this supposition is strongly supported by the relations of the lake beds of Lemhi County.

Deposits known as the Idaho formation, laid down in valleys cut in the Payette, appear along Snake River in Idaho. They are of Pliocene age, though similar to the Payette and in places grading into it. Deposits of this age were not recognized in Lemhi County, although it is possible that the part of the lake beds above the lignitic strata may correspond to them.

Extent of the Miocene lake.—The present studies add a large area to the known Miocene and Eocene (?) lakes of Idaho. It is altogether probable that the entire upper valley of Snake River was occupied by an immense sheet of water into which countless streams draining rugged adjacent areas carried vast volumes of detrital material and on whose surface volcanic ash was showered. Westward the lake may, as outlined by Lindgren,¹ have extended well into Oregon; and eastward it is possible that it reached beyond the Beaver Head Mountains into Montana. At least, beds of similar make-up occur west of Armstead, Mont., and extend beyond the Continental Divide into Idaho in the vicinity of Bannock Pass.

QUATERNARY SYSTEM.

PLEISTOCENE DEPOSITS.

Topographic features characteristic of glaciation are conspicuous at elevations greater than 7,500 feet, although tongues of ice extended down many of the valleys to 7,000 feet and down a few to 6,500 and even 6,000 feet (Panther Creek). Probably the largest single body of ice occupied the Mackinaw district, where an area of 200 square miles was probably entirely covered. Another large ice field, possibly connecting with this by way of Baldy Mountain, occupied the highland about Prairie Basin, where the terminal moraine crosses Panther Creek at an elevation of 6,000 feet. Within these areas rolling surfaces, lakes and marshes, valley trains, U-shaped valleys (which give way to V-shaped valleys below), striated boulders, and the like are common.

The canyons heading against the Beaverhead Mountains and Lemhi Range north of Junction, are narrow up to altitudes of 7,000 to 7,300 feet, where they abruptly widen, the sides becoming steeper and the floors broad and hummocky. These features continue until the walls merge into a steep-sided amphitheater or cirque, within which a little lake may be expected though not always found. South of Junction, owing to the altitude of the main valley, many of the mountain valleys are glaciated through their entire length. Their terminal moraines, pushed by the ice out upon the valley flats,

¹ Lindgren, Waldemar, Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, p. 96.

appear as crescent-like ridges. Such moraines are beautifully developed about the mouths of Meadow Creek gulch (Pl. V, *B*, p. 34) and of Long Canyon. So clear are the marks of glaciation that the Pleistocene serves as a valuable datum line in the area.

IGNEOUS ROCKS.

ARCHEAN GNEISS.

Coarse-textured granite gneiss occupies a broad area in the north-western part of the county. It is typically developed in the canyon sides about Shoup, along the lower course of Big Creek, and on Owl Creek.

The formation is separated from the overlying schists by a profound erosional unconformity, clearly shown in a few small exposures along the road from Shoup to the Kentuck mine. In most places weathered particles of gneiss enter into the lower few feet of the schist, forming an arkose, but elsewhere coarse undecomposed feldspar crystals appear at the very contact. (See Pl. VI, *B*.) The gneiss is thought to be an intrusive rock, although the local evidence of this is little more than suggestive. In a few places within the gneiss are small masses (up to 4 feet) of fine-grained micaceous material. A conspicuous example appears in the face of a large block which lies beside the trail about one-fourth mile above Shoup. As seen in the field these areas suggest inclusions of mica schist, and such they may be, but if so they have assumed a mineralogic make-up very similar to that of the gneiss, save for a higher percentage of biotite. From the broad theories of geology, however, and as in most places where similar granitic rocks have been thought to be portions of an original earth crust they have proved to be intrusive into older sediments, the rock is believed to be intrusive. Because of its relation to the overlying Algonkian it is assigned to the Archean.

The gneiss presents a striking appearance in natural exposures. Numerous large feldspar crystals, crushed into thick lenses, interleave one with another, separated only by bands of biotite which bend about them. Quartz, all of which is crushed, is scattered through the biotite bands and among fragments of feldspar. Magnetite crystals are scattered through the finer-grained parts. The feldspar crystals on account of their length, which probably averages 1 to 2 inches and over large areas 3 to 4 inches, are most resistant to weathering and present a nodular aspect on exposed surfaces. They are especially coarse near the mouth of Beaver Creek, where one individual measured 18½ inches. Plate VI, *A*, illustrates a typical specimen.

Microscopically examined, the rock is seen to be made up of orthoclase with micropegmatite, quartz, and biotite in subordinate

though conspicuous amounts. Oligoclase, muscovite, apatite, magnetite, and diopside are accessory and decreasingly important in the order named. Many of the feldspars are crushed; many of the biotites are broken and bent and others recrystallized; quartz is fractured; and apatite crystals show many cross cracks.

The schistosity planes vary markedly in attitude from place to place, some being flat but most of them dipping at a high angle southwest and a few northeast. The prevailing strike is about N. 20° W.

LATE CRETACEOUS OR EARLY EOCENE GRANITE.

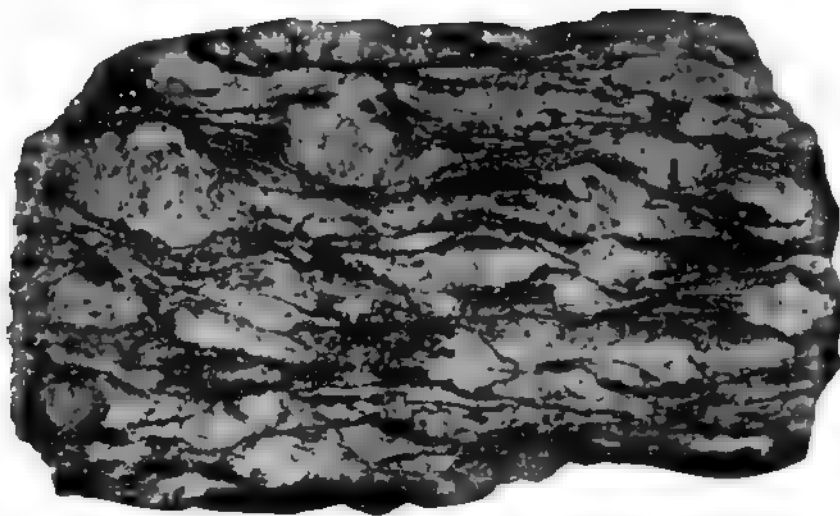
Granitic rock is widely exposed in Big Creek canyon and along Salmon River from Shoup eastward to Dump Creek, but on the adjacent uplands it is concealed by the Algonkian sedimentary rocks. The occurrence west of Salmon, where it forms the divide, is an exception. The rock is also exposed about the head of Yellow Jacket Creek and at three places along the western slope of the Beaverhead Mountains; one near the head of Boyle Creek, another in the northern part of the Nicholia district and, intermediate between the two, a dioritic facies in the canyon of Little Eightmile Creek.

The granite is of light-gray color and of medium texture, with some phenocrystic development of feldspars. In the field it appears to be fairly uniform in composition, but when it is examined in thin sections it shows marked variations. The persistent constituents are orthoclase, quartz, and biotite, although the biotite is rather variable in amount. Among accessory minerals zircon, apatite, and magnetite are usually present. Microcline is locally very abundant (Queen of the Hills mine) as is also perthite, and the more acidic varieties of plagioclase feldspar are generally represented. Indeed, it is probable that more detailed studies will establish all gradations between the normal granite, the quartz diorite exposed on Little Eightmile Creek, and that found in the Texas and Spring Mountain districts, where no orthoclase was noted. The quartz diorite is a dark-gray fine-grained holocrystalline rock composed of plagioclase (about oligoclase) and a little orthoclase, quartz, biotite, and hornblende.

In the northern part of the State, in the Bitterroot Range and the Clearwater Mountains, where granitic rock prevails, its general composition is near that of quartz monzonite, although gradations to normal granite on the one hand and to diorite on the other are recorded.¹ Also in the southern part of the State, in the Wood River district, the granite and diorite blend into each other.²

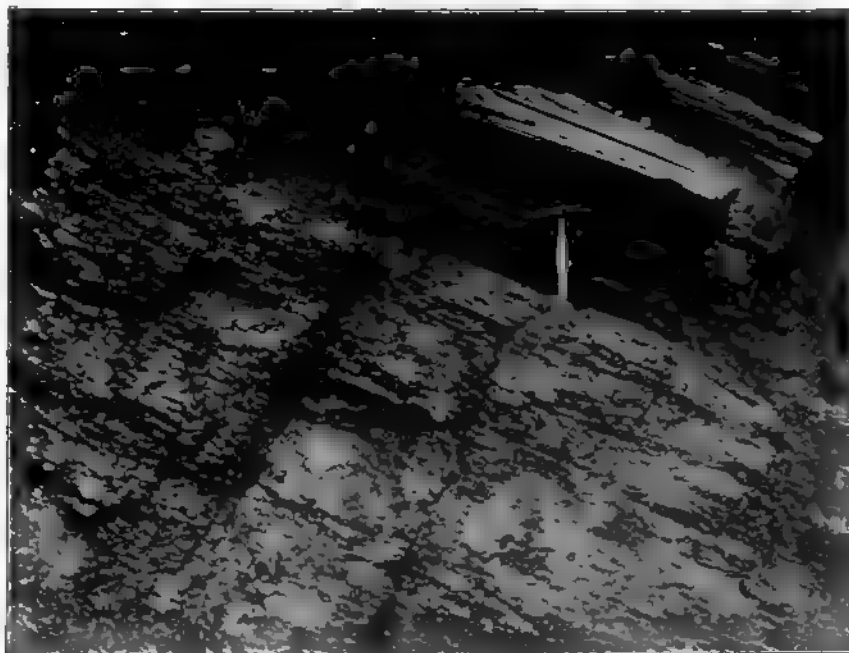
¹ Lindgren, Waldemar, A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: Prof. Paper U. S. Geol. Survey No. 27, 1904, pp. 17-20.

² Lindgren, Waldemar, The gold and silver veins of Silver City, De Lamar, and other mining districts in Idaho: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, p. 195. For extent of granite area, see Pl. VIII.



1. POLISHED SURFACE OF ARCHEAN GNEISS.

The elongated feldspar crystals are surrounded by folia of biotite (black) and crushed quartz (white).
One-half natural size.



B. CONTACT BETWEEN ARCHEAN GNEISS AND ALGONKIAN SCHIST ONE-HALF MILE NORTH-
WEST OF SHOUP

Separated by an erosion unconformity, which, however is not definitely shown

The granite is clearly post-Carboniferous, and in the northern part of the State its relation to supposed Triassic sediments shows it, with the same degree of certainty, to be post-Triassic. Truncated by an Eocene erosion surface, the granite is clearly older than, say, middle Eocene. Narrower limitations are not afforded within the present area, but broad considerations lead to the opinion that the granite was intruded during late Cretaceous or early Eocene time. It has been shown (p. 25) that Eocene erosion, probably developing a continuous surface of gentle relief, operated over much of Idaho, western Montana, northeastern Washington, and northward into the Interior Plateau of Canada. One of the evidences that this surface is of Eocene age is the vast volume of Eocene sediments which border it. It is noteworthy (fig. 6, p. 28) that the granite is widely exposed within the eroded area but is absent within the area of Eocene sediments. It is scarcely conceivable that a magma of the magnitude of the one here represented, which occupies a large part of Idaho and extends into adjoining States, could intrude the formations of the region without being accompanied by an extensive raising of the general surface. Granting that the granitic intrusion caused or accompanied a profound elevation of the area which supplied the Eocene sediments, it remains to be ascertained whether or not it determined the particular elevation involved. Neither Jurassic nor Cretaceous sediments show any special development adjacent to this area, and those of Triassic age are supposed to have crossed it. These general considerations lead the writer to the belief that the broad elevation which resulted in the Eocene surface accompanied the granitic intrusions and therefore that the granite is of late Cretaceous or early Eocene age.

If this assignment of the Idaho batholith is correct, it is much younger than the great intrusive body of the Sierra Nevada of California and is probably younger than the Coast Range batholith of British Columbia and Alaska. The former is definitely known to be of late Jurassic or early Cretaceous age;¹ the latter is less definitely assigned to the early Cretaceous.²

DIKES.

DISTRIBUTION AND CHARACTER.

Dikes are widespread in Lemhi County and locally are very numerous. They attain their maximum numerically in the Yellow Jacket district in the west-central part of the county, where twenty-five or thirty averaging 20 to 50 feet in width parallel each other along a belt perhaps a mile wide. They are also conspicuous about Shoup

¹ Diller, J. S., *Geology of the Taylorsville region, California*: Bull. U. S. Geol. Survey No. 353, 1908, pp. 89-90. Also see the numerous folios of the *Geologic Atlas* covering parts of the Sierra Nevada.

² Knopf, Adolph, *Geology and mineral resources of the Eagle River region, Alaska*: Bull. U. S. Geol. Survey No. 502, 1912, p. 27.

and in the southern end of Lemhi Range. Along the Continental Divide and in the Eureka, Mackinaw, and Gibbonsville districts dikes are rare, but in the Blackbird and Indian Creek districts they are common.

These intrusives range in width from a few inches to 1,000 feet (Spring Mountain), those about 40 feet across being most abundant.

The dikes of the area present many types of rock, but granite and rhyolite porphyries, diorites, and quartz diorites are most numerous. Lamprophyres (minettes and vogesites), aplites, and pegmatites appear locally, as do also gabbro, basalt, and dacite, syenite, trachyte porphyries and peculiar monzonites. In the following sections each kind is described briefly and its known distribution outlined. It is noteworthy that the different kinds seem to occur in all associations.

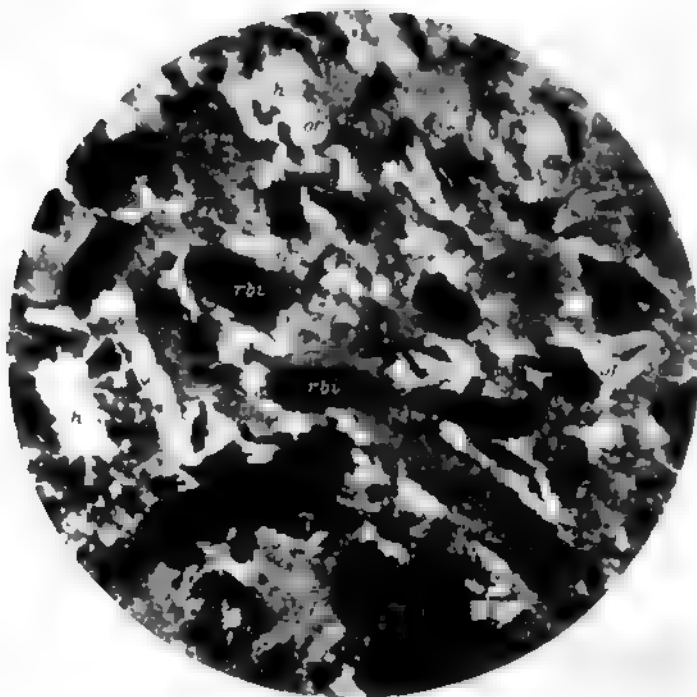
TYPES.

The granite porphyry dike rock varies in appearance from coarse porphyritic rock with phenocrysts of orthoclase as much as an inch in length and quartz of wheat-grain size thickly set in a fine-grained blue-gray groundmass to a light-gray rock of almost equigranular texture. Intermediate between the two extremes is a dark-gray variety studded with orthoclase and quartz crystals from an eighth to a quarter of an inch in length. Biotite is commonly present. Granite porphyries were noted in the Mineral Hill, Mackinaw, and Junction districts, in the northern part of the county.

Dikes of rhyolite porphyry occur in the above-named districts and also in many places in the lava-covered belt defined later. They are commonly light gray to dove-colored, but in places pale shades of green or brown predominate. Although they are similar to the granite porphyries, their crystallization is much less advanced, the groundmass being glassy to microcrystalline and constituting perhaps three-fourths of the volume.

Dikes of quartz diorite porphyry have perhaps a wider geographic distribution in the area than those of any other type, although in no place are they very abundant. They are found throughout the southeast part of the county and in the Yellow Jacket, Gibbonsville, and Mineral Hill districts. On account of their brilliant medium-sized feldspar, quartz, biotite, and some hornblende crystals, set in a fine-grained variegated groundmass of the same material, these rocks are the most beautiful found in the area.

Diorite and diorite porphyry dikes occur inconspicuously in many parts of the county, but attain a marked development about the head of the Lemhi Valley. They vary considerably in texture but are commonly medium to fine grained and about equigranular. The constituent minerals are plagioclase (oligoclase-andesine), hornblende, biotite, and a little quartz.



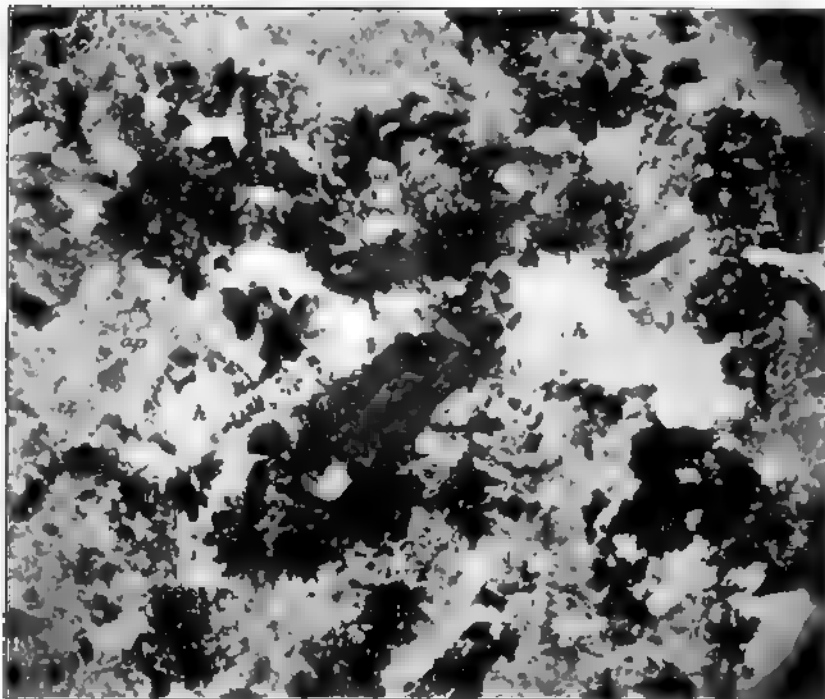
A. MINETTE FROM BROOKLYN CLAIM, BLACKBIRD DISTRICT.

orr. Orthoclase, *rbt*, biotite with much rutile included; *bt*, biotite free from rutile, which seems to have been added in the *rbt* crystals, *h*, hole in section. Enlarged 35 diameters; nicols parallel.



B. VOGESITE FROM GEERTSON CANYON

q, Quartz; *hb*, hornblende, *or*, orthoclase. Note the angular area of quartz inclosing hornblende and with hornblende clustered along its contact. Enlarged 35 diameters; nicols parallel.



A. BIOTITE MONZONITE FROM ITALIAN MINE

f. Feldspar, both orthoclase and oligoclase; *bt*, biotite; *ap*, apatite; *h*, hole in slide. Enlarged 35 diameters, nicols parallel.



B. HORNBLENDE MONZONITE FROM YELLOW JACKET HILL

or, Orthoclase; *ol*, oligoclase showing zonal extinction with core Ab₂An₈; *hb*, hornblende; *bt*, biotite; *q*, quartz; *ap*, apatite; *r*, calcite. Enlarged 35 diameters, nicols parallel.

Rocks of the lamprophyre class are represented by minette and vogesite. They are fine grained and dark gray to blue-black in color. A typical minette from the Brooklyn claim, in the Blackbird district, in the northwestern part of the county (see Pl. VII, *A*), consists of biotite (possibly 40 per cent), orthoclase, a little plagioclase, and chance crystals of hornblende. Rutile is beautifully developed as thin needles in the biotite, oriented along the directions of its percussion figures. Micropegmatite is common though not abundant as an interstitial filling. Apatite is an abundant accessory mineral, and titanite is rare. Epidote and zoisite are secondary. Structurally this rock is characterized by a phenocrystic development of biotite, which is set in a groundmass of feldspar and biotite. Thus there are two distinct generations of biotite.

Vogesite from Geertson Creek canyon consists of orthoclase and hornblende (estimated as 40 per cent), with subordinate amounts of micropegmatite, quartz, and plagioclase. Scattered through the rock are fragment-like grains of quartz as much as 3 or 4 millimeters in diameter. These are surrounded by clusters of hornblende needles which in places are embayed in the quartz near its margin. Apatite, titanite, and rutile are accessory. (See Pl. VII, *B*.) The structure of the vogesites is dominated by a phenocrystic development of lath-shaped hornblendes.

Lamprophyric dikes were noted at places along the Continental Divide north of Agency Creek and in the Blackbird and Yellow Jacket districts.

A biotite-rich rock, perhaps best classified as biotite monzonite, although closely related to the lamprophyres in composition, occurs near the Italian mine, in the Leesburg basin. It is a dark-gray fine-grained equigranular rock, which in the hand specimen seems to be made up of about equal amounts of orthoclase and ferromagnesian minerals. On microscopic examination it is seen to be inequigranular and composed of orthoclase, biotite (estimated as 20 per cent), albite, oligoclase, and quartz, the last in very subordinate amounts. Abundant apatite and less titanite and diopside are accessory. Zoisite and epidote are secondary. (See Pl. VIII, *A*.)

A similar rock, but rich in hornblende and containing more sodic feldspar, occurs near the Yellow Jacket mine and is classified as hornblende monzonite. (See Pl. VIII, *B*.) It contains about 20 per cent of hornblende and 5 per cent of biotite. Plagioclase (principally oligoclase) is slightly in excess of orthoclase. Quartz is conspicuous though not abundant. Micropegmatite is beautifully developed locally. Apatite, rutile, and titanite are the chief accessory minerals; calcite, epidote, and zoisite are secondary.

Dikes, probably to be classed as pegmatites, appear near the lower granite contact on Pine Creek, in the northwestern part of the county.

They are light gray and are made up principally of feldspar, quartz, and muscovite. The small number of pegmatite dikes about the border of the granite mass is noteworthy and seems to be a feature characteristic of the entire Idaho batholith, as from no place about its border have important pegmatites been reported.

Aplitic dikes are well developed in the Indian Creek district in the northern part of the county. They are light-gray fine-grained microcrystalline feldspathic rocks sparsely studded with quartz grains perhaps as large as a pinhead.

Gabbro was seen only in the Blackbird district. It is a blue-black holocrystalline rock consisting of pale-green hornblende, diopside, plagioclase (oligoclase-andesine), and biotite, with accessory pyrrhotite, pyrite, titanite, and apatite.

A mottled gray rock, made up of feldspar crystals as much as an inch in length set in a finely crystalline groundmass which constitutes perhaps half the mass, occurs near Yellow Jacket and is classed as monzonite porphyry. In the specimen studied phenocrysts of andesine, oligoclase, and orthoclase occur in about equal amounts. The groundmass is not determinable.

Dikes of basalt occur in a few places in the Gibbonsville and Mineral Hill districts as narrow fillings, but none of them are important.

Dikes of dacite porphyry have been produced by quartz diorite intrusions that entered very narrow fissures.

Syenite porphyry was noted at only one place, one-fourth of a mile south of Noble, in the northern part of the county, but has been reported from the Yellow Jacket district. The rock seen is light gray, coarse to medium grained porphyritic, with phenocrysts of orthoclase, scattered hornblende, and a very few quartz grains. The rock is generally badly altered, much zoisite, sericite, and epidote being developed.

AGE OF DIKES.

Representatives of all the types of dikes above described were truncated by the Eocene erosion, and as none of them bears evidence of being older than the granite and some are inclosed in it, it is probably safe to assume that they are all younger than the granite. Thus it appears that dikes of the varieties here described were intruded after the granite and before the close of the Eocene—in other words, after the Archean period of igneous activity and before the late Tertiary. These dikes are therefore considered a later phase of the late Mesozoic or early Tertiary volcanic epoch, of which the great granite batholith of Idaho is the dominant expression. Although most of the dikes of the area are thought to belong to this group, it can not be assumed that they all do, for obviously there are intrusive facies of the late Tertiary lavas. On the other hand one of the diorite dikes (possibly a sill) found at Gibbonsville is sheared and jointed in a manner to suggest that it is older than the granite.

TERTIARY LAVAS.

A great belt of Tertiary lavas extends from a point near the Beaver Head Mountains on Agency Creek southwestward past Parker Mountain. These lavas occupy summits and valleys, Salmon Canyon being cut in them most of the way from Salmon up to the mouth of Pahsimeroi River, and the highest summits on either side being capped by them. Smaller areas of volcanic rocks appear west of Gibbonsville, on Moose Creek, and in the south end of the Leesburg basin.

The lavas include rhyolites, andesites, latites, basalts, trachytes, and dacites, the last two being very subordinate in amount. Rhyolites are perhaps most widespread, being extensively developed in the Parker Mountain and Gravel Range districts, along Salmon Canyon above Salmon, north of Junction, along Napias Creek below California Bar, and near Noble. They are commonly light gray and show distinct flow lines. Orthoclase and a little biotite appear as scattered phenocrysts in a cryptocrystalline groundmass, which is made up largely of microlites of feldspar, but which becomes glassy locally.

Second in importance perhaps are andesites, which have much the same distribution as the rhyolites except that they are very subordinate in the Gravel Range and Parker Mountain districts. They present a variety of colors from dark resinous brown through many shades of pink and purple to gray. In general the microcrystalline groundmass predominates over the phenocrysts, which are plagioclase (about oligoclase-andesine), biotite, hornblende, and in some of the flows (as on Salmon River south of Salmon) augite.

Latites are also present in the series, but in what proportion is not known. A specimen of what was thought from microscopic study to be a typical andesite proves on partial chemical analysis to be a latite. It is possible that other of the andesites would prove on analysis to be latites.

The analysis follows:

Partial analysis of latite from divide on the Yellow Jacket-Forney road, Idaho.

[W. T. Schaller, analyst.]

SiO ₂	62.86
CaO.....	4.30
K ₂ O.....	3.12
Na ₂ O.....	3.26

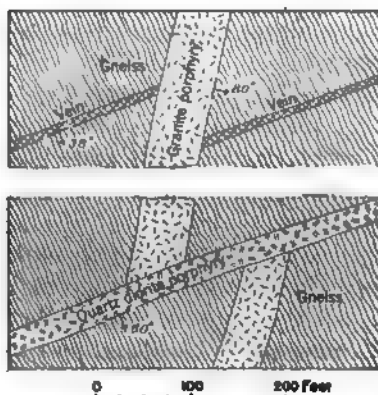


FIGURE 8.—Sketch of exposures near the Kan-tuck mine, Mineral Hill district, showing geologic relations.

The rock is a porphyritic lava of purplish hue in which phenocrysts are slightly subordinate to the groundmass. The groundmass is microcryptocrystalline and is studded with phenocrysts of plagioclase (about oligoclase-andesine), and a few of hornblende and biotite. The ferromagnesian minerals are commonly surrounded by resorption zones, some of which entirely replace the crystal. From the microscopic studies there appears to be little doubt that most of the potash and much of the silica is in the groundmass.

Basalts also are widespread, perhaps reaching their maximum development just below the confluence of Pahsimeroi and Salmon rivers and in the hills about Agency. A noteworthy occurrence is near the summit of Baldy Mountain. They are fine-grained bluish-black rocks of normal composition, except that olivine is absent in some places (Agency Creek) and is very conspicuous in others (Baldy Mountain). Should this difference prove sufficiently persistent to define two ages of basalt that of Baldy Mountain will be the older.

A specimen which proves to be dacite was procured near the junction of Phelan and Napias creeks. It resembles the andesites of the same locality, but contains phenocrystic quartz and some hypersthene.

Trachyte, similar to rhyolite, but without quartz, was noted in thin beds in the Gravel Range and Parker Mountain districts.

All the lavas occupy valleys developed after the elevation of the Eocene erosion surface, and so far as seen all are thought to be preglacial. In some places, however, they underlie the Miocene lake beds (mouth of Williams Creek), in others they are interbedded (?) with those beds (3 miles west of Salmon), and in still others are poured out upon their extensively eroded surface. From these relations it appears that the lavas date from late Oligocene or early Miocene to about the close of the Pliocene. Of the different types of lava rock, basalts predominate among the youngest and probably rhyolites predominate among the oldest, although alternations seem to be present throughout. This general succession of eruptive rocks corresponds with that recorded for southwestern Idaho.¹

EPITOME OF GEOLOGIC HISTORY.

The geologic history of the area includes granitic intrusion followed by profound metamorphism, erosion, and sedimentation in pre-Cambrian time, and sedimentation in Cambrian, Ordovician, Silurian(?), Devonian, and early Carboniferous time. After the Paleozoic the record is not legible until rocks are reached that represent late Cretaceous or early Eocene time, in which the granite mass of central Idaho, which forms one of the larger batholiths of the

¹ Lindgren, Waldemar, and Drake, N. A., Silver City folio (No. 104), Geol. Atlas U. S., U. S. Geol. Survey, 1904, p. 3.

North American Continent, formed beneath the area. The Eocene epoch was spent in reducing the uplift which is thought to have accompanied the granite intrusion. After the area had been reduced well toward the base level of erosion it was elevated to about 8,500 feet above the sea, and a new physiographic cycle was begun. The rejuvenated streams developed broad valleys, in places 5,000 feet or more deep, and in these valleys extensive lake beds were formed during Miocene time. During the Miocene also lavas were poured out and at its close thick beds of tuff were formed. Since then erosion has been dominant, the drainage being southward at first and later westward, through Salmon Canyon, lavas being again poured out after this change in the direction of the drainage. During the Pleistocene epoch glaciers capped the summits and occupied the larger valleys down to elevations of about 7,000 feet, rarely to 6,000 feet.

The area has passed through several periods of diastrophic movement. Each of the four older formations is metamorphosed, faulted, and folded more than the one next younger. Broad and pronounced elevation took place at the beginning and at the close of the Eocene and to a subordinate extent after the end of Miocene time, the post-Miocene uplift being recorded by minor faulting and folding in the lake beds and by an east-west anticline through the Texas district.

It is noteworthy that, although since the earliest Paleozoic time no important regional metamorphism has been recorded in the area, yet the schists and gneisses of pre-Cambrian age record profound dynamic disturbances.

ORE DEPOSITS.

GENERAL FEATURES.

CHARACTER OF DEPOSITS.

The principal ore deposits found in Lemhi County, Idaho, are fissure veins and replacement deposits along shear zones. In some places the metallic minerals occur in joints and crevices in the country rock (Italian mine), but elsewhere replacement has occurred along bedding and joint planes (fig. 15, p. 106). Again, ore minerals occur as disseminations in the country rock (Beliel group of claims) and possibly even as magmatic segregations in diabase (Togo claim). In general, however, the deposits are tabular and clearly to be classed as veins. Two epochs of mineralization are recognized—late Cretaceous or early Eocene and late Miocene or early Pliocene. All the deposits except a small group of gold-silver veins belong to the former epoch. The deposits may be grouped, according to the leading metal contained, as gold, lead-silver, copper, cobalt-nickel, and

tungsten deposits, and they will be treated in the order named. In the past only the first four metals have been produced, but recently tungsten has been exploited, and in the future the cobalt and nickel deposits, though of low grade, will probably be worked. The total production of the county is about \$20,000,000, two-thirds of which has come from gold, three-fourths of the remainder from lead, and the balance from silver ores, save for about \$40,000 derived from copper.

DISTRIBUTION.

For several years after the discovery of gold placers on Napias Creek in 1866 and of lode deposits at Yellow Jacket in 1868 gold was the principal metal sought. About 1880, however, lead-silver deposits were discovered near Nicholia, in the southwest part of the county, and were exploited successfully during the next decade. This led to the locating of many lead-silver properties in adjoining areas, and although most of them were not worked for several years some of them have recently proved to be among the most valuable lode deposits known in Lemhi County. Copper has played a very subordinate part in the economic development of the area. It was first recognized in 1883, when the Copper Queen mine was located, but as this property at that time was held for gold perhaps the first copper locations may be considered as those made in 1896 in the Blackbird and Mackinaw districts. Nickel and cobalt were first recognized in 1901, and tungsten was discovered in 1903 on Patterson Creek.

Nineteen mining districts, including nearly all the upland area except that adjacent to Salmon Canyon above Salmon, are recognized in Lemhi County. Their position and approximate area are shown on Plate I (in pocket). Gold is the most widely distributed valuable metal, occurring in commercial quantities in all the districts except three located about the headwaters of Lemhi River. Silver generally accompanies the gold, but in very subordinate amounts, its chief occurrence being in the lead ores which are found only about the head of Lemhi Valley. Copper occurs in a broad belt extending across the center of the county from east to west, and in the vicinity of Spring Mountain in the southeast part of the area. Cobalt and nickel have been recognized only in the Blackbird district, 40 miles southwest of Salmon. Tungsten, so far as known, is confined to a small area adjacent to Patterson Creek, near the head of Pahsimeroi Valley.

GEOLOGIC RELATIONS.

The geologic history of the area includes the formation of great granitic masses in Archean time, probably as batholithic intrusions; extensive sedimentation in the Algonkian; deposition of dolomitic limestones, limestones, shales, and quartzites in the Paleozoic; gran-

ite intrusions in the late Cretaceous or early Tertiary, followed by the intrusion of dikes of various kinds; profound erosion in the Eocene; flows of lava and sedimentation in lakes in the Miocene and Pliocene (?); and glaciation of areas higher than 7,000 feet in the Pleistocene.

The Archean gneiss occupies the northwestern part and the Paleozoic sedimentary rocks the southeastern part of the county; between them is a broad belt of Algonkian sedimentary rocks. Granite is most widely exposed west of Salmon, but isolated patches are reported at three widely separated places along the Beaverhead Mountains. Dikes appear in all parts of the county but are most numerous in the vicinity of granite outcrops. Tertiary lavas extend in a broad belt from a point near Lemhi Pass southwestward beyond Parker Mountain, and lake beds, older than most of the lavas, occur principally along the larger valleys of the area.

Gold-bearing veins are inclosed in many types of rock in Lemhi County, ore deposits both older and younger than the lavas being clearly recognized. It is noteworthy, however, that only one deposit of gold has been found within the area of the Paleozoic formations. It is also noteworthy that the gold is principally in the vicinity of rock of the granite-rhyolite family. Lead-silver ores, on the other hand, occur only within the area of Paleozoic sedimentary rocks, and here quartz diorite is the only igneous rock recognized. Copper occurs principally within the area of Algonkian sedimentary rocks, although one deposit is known within those of Paleozoic age. It has not been found in the Tertiary lavas nor in the granite; indeed in most places it is at a considerable distance from either, although it is thought to be genetically related to the granite. Cobalt-nickel and tungsten occur within the Algonkian rocks. Diabase dikes are associated with the cobalt-nickel ores, but no igneous rocks were noted in close proximity to the tungsten-bearing veins.

GOLD DEPOSITS.

PLACERS.

DISTRIBUTION.

The older gold veins of Lemhi County have given rise to placer deposits wherever local conditions permitted their accumulation. Over a large part of the area, however, rapidly flowing streams lead from the sites of vein disintegration into larger streams which also are actively eroding their channels, thus affording no point where material transported by the torrential water may be permanently dropped. This condition accounts for the absence of placers around Shoup, Ulysses, and Gibbonsville. In a few places, however, gold veins are ideally situated for the accumulation of placers and valuable deposits have been found. Streams heading near the crest of the

Beaverhead Mountains flow swiftly through narrow canyons, gathering abundant detrital material and transporting it to the broad, gently sloping valley of Lemhi River, in crossing which the decided lessening of stream grades allows the heavier and coarser material to be substituted for the finer-textured constituents of the valley formation. Thus the auriferous gravels have accumulated along Bohannon and Kirtley creeks near the base of the range and to a less extent along other creeks leading from the same mountains. The upper valleys of Napias and Moose creeks have also been favorable localities for the accumulation of gold placers. At the latter place streams from the surrounding highlands sorted their load and dumped the heavier parts of it in crossing an old sediment-filled lake basin. In the former the gravels were similarly sorted and deposited on the floor of a broad valley.

Placers have been found also near the mouth of Beaver Creek, on Silver Creek near Rabbitfoot, below Yellow Jacket, and at several other localities, but the extent and production of all of these is comparatively negligible.

PRODUCTION AND HISTORY.

Of the four principal deposits, that of Napias Creek leads in production, having furnished perhaps \$5,000,000 in gold. Gold was discovered on this creek in July, 1866, and during the few years following the deposits were worked actively. Recently only a few Chinamen have been working in the basin and the production has been very small.

Moose Creek, with an output of about \$1,000,000, stands second in production. The placers there were located shortly after those on Napias Creek, but, being under one ownership, were not worked so rapidly and are still being operated. A dredge now on the creek affords an annual output of \$15,000 to \$20,000.

Bohannon Bar, with a production of about \$400,000, ranks third. The creek bed was worked by Chinamen many years ago, but not until 1895 were preparations made for hydraulicking the adjacent benches. At present one giant is being operated on the bar with an annual recovery of about \$17,000.

On Kirtley Creek hydraulic mining was pursued from about 1890 to 1894 and a considerable amount of gold was recovered, but operations were abandoned and the property sold as acreage. Recently the low bars adjacent to the creek were carefully prospected by a California dredging company, which has since purchased it and is now installing a large dredge.

ORIGIN OF PLACER GOLD.

In most of the placer deposits the gold can be directly traced to veins, lenses in schist, or stringers along fracture cracks. It has been generally true, however, that the primary deposits have not proved

comparable in value to the placers formed from them. Thus in the Leesburg basin the placers have produced approximately \$5,000,000 and the lode deposits probably not more than \$225,000. In the Moose Creek basin the difference is almost as great, \$1,000,000 being yielded by the placers and less than \$75,000 by the veins which supplied them. Bohannon Bar has been a productive placer ground, but lode deposits above it have never proved valuable. The same is true to a lesser extent of Kirtley Creek.

At the head of Bohannon basin no vein deposits have been found, although numerous quartz stringers, an inch or two in width, traverse the Algonkian rocks at several places. It is probably from these insignificant deposits that the placers have been derived. About Moose Creek basin also the origin of the gold seems traceable only to unimportant stringers which traverse the schists east of the basin. Near the north end of this zone the Shoo Fly mine supplied bullion worth possibly \$75,000. Most of this was derived from quartz material strewn loosely over the surface, and when search was made for a permanent vein beneath none was found. The quartz seems to have occurred as lenses in the schist, many of them of small extent. In the Leesburg basin deposits which have shown a fair degree of persistency have been discovered, but their metallization is so erratically distributed that, with the exception of the Italian property, they have not been worked at a profit. At the head of Kirtley Creek basin veins affording some bullion have been worked.

CHARACTER OF THE PLACER DEPOSITS.

In general the auriferous gravels are made up of material as large as 2 feet and averaging perhaps 6 or 8 inches. Gravel and sand fill the interstices between the larger boulders, and the entire deposit is cemented loosely by silica. The average thickness of the gravel beds is 17 to 18 feet, but in some places it is less than 10, and in others, as in the upper benches of Bohannon Bar, as much as 31 feet. Nearly all the gold is found in the lower 2 or 3 feet of the gravels and the upper 18 inches of bedrock, although locally the lower 8 or 9 feet of the deposits are auriferous. The gold ranges in size from small flakes up to the type commonly known as "shot gold." Very rarely nuggets worth \$2 or \$3 have been found. A gradation from coarser grains near the head of the deposit to finer near its lower extremity is generally reported and is especially noticeable on Kirtley Creek.

AGE OF PLACERS.

Placer deposits within Lemhi County range in age from Miocene to present. The oldest beds recognized are near the mouth of Kirtley Creek canyon, where an attempt was made several years ago to wash the Miocene lake beds, which are known to contain some gold near

their margin. The series here consists of shales, sandstones, and conglomerates. One of the conglomerates, which occurs about 50 feet below the top of the cliff and overlies a bed of shale, is said to contain gold in commercial quantities, and lesser amounts have been found at other horizons. The most important deposits of the area are probably of late Pliocene age, and to this class belong the gravels now being exploited on Kirtley Creek, those on Bohannon Creek, those on Moose Creek, and most of the placers in the Leesburg basin. Placer gold of post-Pleistocene age occurs below Leesburg and on Phelan Creek, where bedrock is made up of glacial till. That placers are accumulating even at the present time is illustrated at the Haidee property on Arnett Creek in the Leesburg basin, where the ground is washed each spring in order to secure gold which has been freed by the disaggregation of a highly decomposed granite during the previous winter.

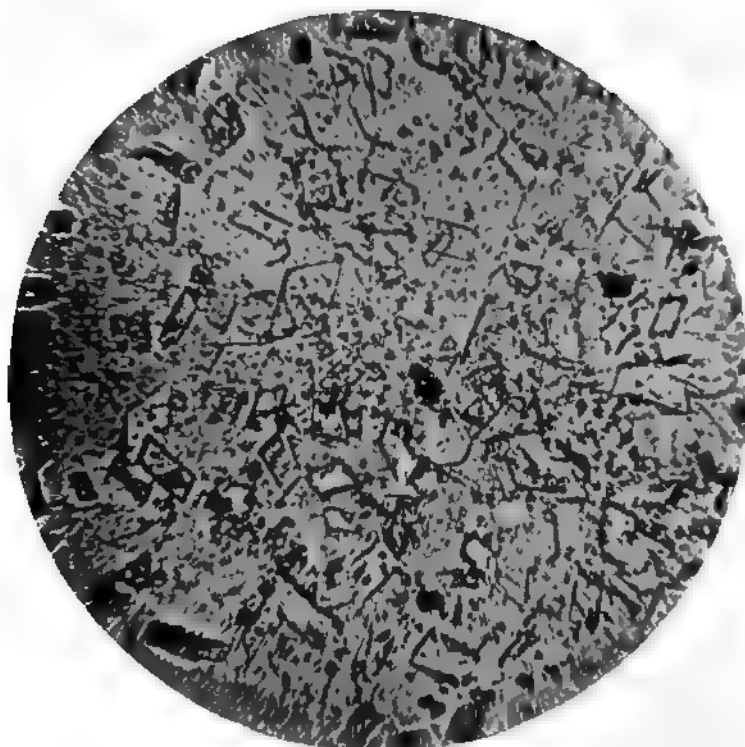
LATE TERTIARY GOLD VEINS.

DISTRIBUTION.

Gold veins of late Tertiary age are known only in the southwest part of the county, in the Parker Mountain and Gravel Range districts, and possibly at Musgrove, in the Blackbird district. The most extensive deposit yet developed is at Myers Cove (Singiser) in the Gravel Range district, where the Monument vein is opened to a depth of 200 feet, with drifts on three levels. Here considerable tonnage of ore is blocked out. At Rabbitfoot an even greater amount of work has been done, although less ore has been found. In the Parker Mountain district two properties have been opened within the past few years and possibly 2,000 feet of tunnels driven. A little ore has been shipped.

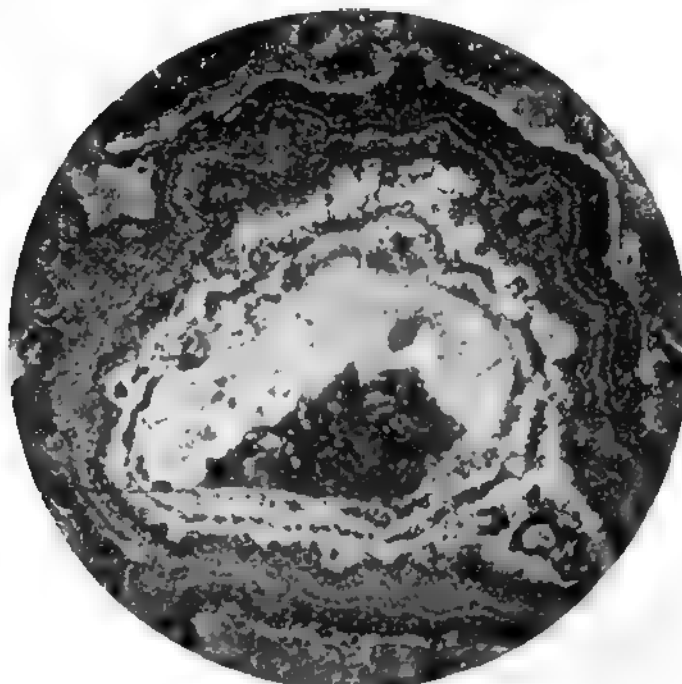
TREATMENT OF THE ORES.

The great difficulty at Myers Cove, where by far the most ore is in sight, has been to devise an efficient method of treatment. Amalgamation tests on roasted ore gave 11 to 20 per cent extraction, cyanide afforded a recovery of 20 to 30 per cent, and a combination of chlorination and cyanidation yielded 70 to 90 per cent. A mill was built in keeping with the last-named tests, but after running a month or six weeks it was abandoned, the total recovery from \$11 ore being, it is said, less than \$2 a ton. Other properties containing this type of ore have not been developed below the zone of oxidation, but it is probable that with greater depth refractory ores similar to those at Myers Cove will be encountered. The failure to reduce profitably the Myers Cove ore should not be given undue weight, however, for remarkable advances have been made during the last few years in the treatment of similar ores. The production from this group of veins has not been large, probably less than \$100,000.



A. VEIN MATERIAL FROM LATE TERTIARY VEINS IN DOMINION MINE AT MYERS COVE

Showing relations of adularia (rhombohedrons) to quartz. The section was photographed out of focus in order to accentuate the contacts of feldspar and quartz. Dark specks are pyrite and some metallic mineral, possibly a selenide. Enlarged 480 diameters, nicols parallel.



B. VEIN MATERIAL FROM PARKER MOUNTAIN MINE

Crustification is due to alternating layers of the same composition but of different textures. The core is a fragment of rhyolite wall rock. Enlarged 35 diameters, nicols parallel.

GEOLOGIC RELATIONS.

The late Tertiary gold veins are associated with eruptive rocks, principally rhyolites. All the deposits except those at Musgrove are inclosed in lavas. The Musgrove deposits are in Algonkian schists and quartzites, but here rhyolites form the summits and numerous dikes of rhyolite porphyry traverse the older formations. Two series of flows, separated by a structural and erosional unconformity, were noted at Rabbitfoot (see p. 173), but both belong to the same general period of igneous activity. The older eruptives were poured out over a post-Eocene erosion surface of considerable relief and are probably of Miocene age (p. 48); the younger may be early Pliocene.

CHARACTER OF THE VEINS.

The veins in general are strong fissure fillings varying in width up to 10 or 12 feet, but commonly 2 or 3 feet wide. They dip at angles greater than 45° . The internal make-up of the Tertiary deposits is characteristic and distinct from that of the older gold veins, which are vastly more numerous in Lemhi County. The veins are beautifully crustified, consisting of wavy bands, which in their broader outlines are parallel to the walls but in detail close about many cavities not yet completely filled, or encircle angular fragments of wall rock.

ORES.

Locally intergrown with the quartz and less commonly included in quartz grains are very conspicuous amounts of adularia (Pl. IX, A). Calcite is common though never abundant. Sericite is very conspicuous in some specimens from the Parker Mountain mine, but as the ore at that mine is extremely altered it is possible that the sericite, at least in part, has resulted from the breaking down of adularia. The generally crustified appearance of the vein material (Pl. IX, B) is due largely to different degrees of coarseness in alternating layers of quartz.

The metallic minerals, everywhere of microscopic size, are distributed through the ore in dark crimped bands of dull to submetallic luster which parallel the crustification of the gangue. In these bands the metallic minerals occur as bunches of very small particles, fillings between quartz grains, and isolated crystals. Studies were not sufficiently detailed nor development extensive enough to permit satisfactory comparison of the ores from different veins. At Myers Cove, however, pyrite is the most abundant metallic mineral; most of it is contemporaneous with the quartz, many grains of which include pyrite crystals, but it also fills minute cracks formed in the ore at some later time. Owing to the striking similarity between the Myers Cove ores and those at Republic, Wash., which are known to contain considerable amounts of selenium,¹ tests of the former were

¹ Umpleby, J. B., *Geology and ore deposits of the Republic mining district*: Bull. Washington Geol. Survey No. 1, 1910, p. 39.

made in the Survey laboratory and a strong trace of selenium was detected in specimens from the Monument vein. In the Parker Mountain ores a little pyrite is present, but the principal metallic mineral is a bluish-black fine-grained material of bright metallic luster; it was not identified, but its occurrence is similar to that of the pyrite described above, except that it was not noted along fractures. Very heavy iron and manganese stains record the presence of metallic minerals in the Musgrove ores.

The veins carry silver as well as gold, although the latter commonly leads in value per ton. At Musgrove silver is almost negligible, but in some mines at Parker Mountain it is more important than the gold. Within the veins the ore occurs in shoots of irregular shape and size. Thus at Musgrove several veins have been recognized, but only one of them, which runs about \$20 to the ton, is considered of commercial value. At Myers Cove the principal ore body occupies a few hundred feet along one of the veins. Within this shoot individual assays reach several hundred dollars to the ton, but a broad average is said to be about \$10. Promising deposits occur also at Parker Mountain, although their extent has not been shown.

AGE AND GENESIS.

As the veins are inclosed in lavas of Miocene age, they are obviously Miocene or later. On the other hand, valleys several hundred feet deep and evidently of preglacial age, because rounded by glaciers in their upper parts, cross the lodes at Parker Mountain and at Myers Cove. If the later part of the Pliocene is allowed for the development of these valleys, the deposits must have been formed in late Miocene or early Pliocene. The manner in which the veins cross the summits (Parker Mountain and Musgrove) and the valleys (Myers Cove) suggests that only a small amount of erosion had taken place after the extravasations of the lava before the veins were formed. Hence it is thought more likely that they should be assigned to the late Miocene.

The deposits are meagerly developed, and, as only a few days were available for their study, suggestions as to their origin must be by comparison with other deposits rather than by direct observation. The crustification, vug cavities, angular included fragments, fine-grained quartz, and the presence of adularia and selenium, all point to deposition near the surface, probably at depths of less than 3,000 feet. The depositing solutions were evidently rich in silica, potash, and aluminum, and carried subordinate amounts of iron, sulphur, gold, silver, and selenium. It is thought that the solutions were hot ascending waters, probably genetically related to the subterranean disturbance which found its most conspicuous expression in the rhyolitic flows.

SIMILAR DEPOSITS.

The occurrence of selenium at Myers Cove, its probable presence at Parker Mountain, and the possibility that it will be found in the primary ore at Musgrove place one of these deposits and possibly all of them among a rare type of later Tertiary veins which have been recognized in this country only during the last few years. The deposits at Tonopah, Nev., and Republic, Wash., are the only examples of this type of deposit in the United States heretofore described. Both are inclosed in Tertiary eruptive rocks and are characterized by the presence of selenium. The deposits at Tonopah carry selenium but not tellurium, and at Republic selenium is important and tellurium occurs only in traces. Gold-selenium ores have been found at two or three places in Mexico, but the most famous foreign examples of this type are the Waihi veins in New Zealand and the Radjang Lebong deposit in Sumatra.

The deposits above enumerated form a subdivision of a great class of comparatively recent veins which are widely developed in the central plateau of the West, and especially along the western slope of the Sierra Madre in Mexico. They are found in New Mexico, Arizona, southern California, Colorado, Utah, Nevada, Idaho, and at a few localities to the northwest in Oregon and Washington. Throughout, the veins are inclosed in lavas or in rocks once covered by lavas. Fine-textured quartz, a lamellar calcite in many places replaced by quartz, crustification, extensively altered wall rock, bonanzas, absence of productive placers resulting from them, and their associations with Tertiary eruptives, when taken collectively, characterize these deposits.¹

LATE CRETACEOUS OR EARLY EOCENE GOLD VEINS.

DISTRIBUTION AND HISTORY.

The most important gold veins of Lemhi County are of late Cretaceous or early Eocene age. They are widely distributed in the northern and central parts of the county and occur in the McDevitt district on the southeast and the Yellow Jacket district on the southwest. Along the Continental Divide they occur only at elevations greater than 8,000 feet, but elsewhere their distribution is independent of elevation. Thus, in the Mineral Hill district the Grunter vein is near the river level and the Monolith is far up on the canyon side.

Deposits of this type were recognized first in 1868 at Yellow Jacket. During the next 10 years veins were located in the Mackinaw and Gibbonsville districts and later at Mineral Hill and along the Continental Divide. In point of gold production from these older deposits

¹ Lindgren, Waldemar, The geologic features of the gold production of North America: Trans. Am. Inst. Min. Eng., vol. 33, 1903, pp. 804-808.

the Gibbonsville district easily leads with an output of about \$2,000,000. Then follows Mineral Hill with \$750,000, Indian Creek with \$600,000, Yellow Jacket with \$450,000, Mackinaw with \$250,000, and the several other districts of the county each with less than \$100,000. Veins of this type have yielded \$6,000,000 to \$8,000,000 additional through the placers resulting from them. At present, however, the mines have reached base ore and the annual production is much smaller than formerly.

GEOLOGIC RELATIONS.

The late Cretaceous gold veins are inclosed in Archean gneiss, Algonkian sedimentary rocks, Devonian limestone, and Mesozoic granite. In the central part of the area they occur near the contact between the sedimentary rocks and the granite, either in the one or the other. In the Mineral Hill and Indian Creek districts they are in the older rocks, which, however, are traversed by numerous dikes, probably special expressions of the granitic intrusion. At Gibbonsville, on the other hand, the ancient sedimentary rocks are cut only by small basic dikes, the nearest known outcrop of granite being about 12 miles southwest. Along the Continental Divide the veins are inclosed by Algonkian rocks, which are cut in a few places by vogesite dikes, and in one place near the head of Boyle Creek by granite. At Yellow Jacket the unusual number of dikes which traverse the older formation and the existence of contact phenomena not to be assigned to them suggest that granite lies at no great depth, even though not exposed in the immediate vicinity of the mines. (See p. 169.)

NATURE OF THE VEINS.

The strike of the veins varies in different districts. At Gibbonsville it is east and west; at Yellow Jacket northeast-southwest, and along the Continental Divide northwest and southeast. The dip is even more variable, different veins in the same district dipping in opposite directions, as at Gibbonsville. In places, as at Shoup and Ulysses, the veins are remarkably flat, some dipping at angles less than 30° and locally even breaking into horizontal sheets ("big stope," Kittie Burton mine). In width they vary from mere stringers up to 20 feet or more, those which have been worked probably averaging between 2 and 3 feet.

Faulting has been a great handicap to the profitable exploitation of many of the deposits, especially those at Gibbonsville. Difficulties have arisen also from the great variation in width from place to place of individual veins. Many pinch within short distances or break up into numerous stringers following parallel joints or jump to one side and continue along a parallel fissure. Indeed, many of their irregularities may be well conceived by imagining mineral-bearing

solutions rising through country rock traversed by numerous fractures and cross fractures and depositing where local conditions were most favorable.

ORES.

Character.—The deposits are primarily pyritiferous gold-quartz veins. In places chalcopyrite replaces pyrite, as in the copper-gold deposits of the Copper Queen and Copper King mines. Elsewhere pyrite and chalcopyrite are both present, but as a rule either one or the other greatly predominates. The better ore occurs in shoots which have a greater vertical than horizontal extent, and which pitch at angles steeper than 45° .

The vein filling is coarse-textured clear-white quartz, along which the ore shoots occur at irregular intervals. Within the shoots metallization is generally bunchy, with the bunches irregularly spaced. Pyrite is the one persistent ore mineral, and with it the others, one or all, are associated at one place or another. Chalcopyrite is nearly everywhere present, though generally in small amounts. Galena is widespread, though nowhere conspicuous, and sphalerite is equally general but less abundant. Pyrrhotite is rare in the veins and arsenopyrite even more so. Magnetite was noted in two or three of the deposits. Actinolite, chlorite, and epidote are developed in included fragments of schist on Carmen Creek. The several minerals are scattered through the quartz as isolated crystals, fine-grained masses, irregular blotches with quartz intermixed, and patches of coarse crystal aggregates. In places, as at Gibbonsville, the metallic minerals are present locally almost to the exclusion of gangue material, but in general metallization is moderate.

The oxidized ores are free milling, but many of those in which sulphides are predominant yield only 40 per cent by amalgamation. The amount of gold usually varies directly with the amount of pyrite in the ore, save where the ore is cupriferous, in which case it varies with the chalcopyrite. Thus it seems that the gold is principally associated with the pyrite and chalcopyrite, partly free and partly included in these minerals. Throughout it shows a tendency to form placers below the deposits and coarse grains in the oxidized parts of the veins. Silver commonly accompanies the gold, although seldom in amounts greater than a few ounces to the ton.

Few bonanzas have been found in these deposits, although many of the ores are of substantial grade. Probably the highest average grade of ore has come from Gibbonsville, where as much as \$40 a ton has been secured from mill runs, but even there \$10 to \$15 is the common tenor. Elsewhere, average mill runs approximate \$10 a ton, more commonly lower than higher.

Relation of ores to depth.—Throughout the county the base portions of the older gold veins have been reached while development was yet comparatively near the surface—in general within 100 feet

of it. The upper oxidized portions of the veins yielded readily to amalgamation and on the strength of tests made with such material many mills were built only to be abandoned after a few months because the mine workings encountered base ores, which seldom yielded more than 40 or 50 per cent of their gold to amalgamation. In a few places cyanide was tried, but usually with doubtful success, as shown by the fact that not a single cyanide plant was operated in the county in 1910. In general, the presence of a small amount of copper has been the chief deterrent to this method of treatment, but as little or no copper was seen in several of the deposits, it should not prove a universal handicap.

Primary ore once reached, there is no reason for thinking that the deposits do not "go down," but with increase in depth the same irregularities in mineralization and vein outline which occur a short distance below the limit of oxidation must be expected. In other words, the same general characteristics which prevail at 200 feet may be expected at 1,000 feet. It appears impossible to justify a broad statement that the gold deposits of the county become either richer or poorer with depth, the lower limit of oxidation once passed. These conclusions follow from the conditions of deposition clearly recorded in the physiographic and geologic history of the region. Since these veins were formed the entire area has been planed down, a cover of 3,000 or 4,000 feet having been removed. Veins are at present exposed at altitudes differing by 4,000 to 5,000 feet, but it has not been possible to point out any persistent or significant difference, either in form, mineralogy, or tenor, between deposits occurring at the higher elevations and those found at the lower. This being true, an extra thousand feet in depth on most of the veins of the districts should not show persistent changes either for better or for worse.

Relation of ores to granite.—Another consideration, however, concerns the relation of the ores to the granite mass. It is believed (p. 62) that the ores were deposited by solutions given off from or made effective by the granite, and, even though the deposits may not vary with depth from the surface, it may be questioned whether they will not vary with distance from the granite margin. This doubt is not subject to as satisfactory a solution as the other. The only line of evidence seems to be that derivable from the comparative study of groups of deposits found at different distances from the margins of the granite areas, and in assembling the deposits for such groups the possibility of the granite being closer to some deposits than others, though concealed, is a disconcerting factor. Throughout the investigation this factor was borne in mind, and whatever geologic evidence seemed to have a bearing on it was examined. For a time it seemed that in general gold is more closely confined to the granite

margins than copper, but the exceptions are so numerous that the final conclusion is that no definite variation exists.

Secondary concentration.—Within the area as a whole secondary concentration of gold, though not readily recognized, is thought to have been an important factor. At Gibbonsville, however, it is conspicuous, and the deposits deserve special mention in a general discussion. Experience there shows that few veins contained much gold for 15 to 30 or 50 feet below the surface; that for the next 100 feet or so they were comparatively rich and yielded readily to extraction by means of the arrastre; and that below 150 feet they consisted of sulphide ore lower in grade than the ore occurring between it and the surface zone. As this has been the experience of the several operators in the district, there seems little reason for doubting that secondary concentration of gold has generally taken place there.

The problem, then, is to ascertain whether the concentration of gold has been due to the leaching out of other constituents of the vein, and is thus a residual concentration, or has been due to solution and redeposition of the gold itself. The alteration of pyrite to limonite causes an increase in volume of 2 per cent, but at the same time the new form has a gravity about 25 per cent lower than the old. The change thus means a slight decrease of gold per unit volume but a pronounced increase of the number of unit volumes per ton of ore, giving thereby a decided increase in the gold contained in a single ton. Any extraction of iron from the veins operates in the same direction. It is therefore concluded that much of the enrichment of gold in this type of veins is due to volume changes and the removal of iron, but it remains to be seen why the upper 15 to 50 feet should be so much lower in grade than similarly oxidized material lying immediately below it. It has been shown both by experiment and by observation¹ that gold in the presence of manganese is very appreciably soluble in most mine waters at earth temperatures. As manganese is here present as conspicuous stains and dendrites in the oxidized ore, it is very probable that the barren zone near the surface is due to chemical leaching, the gold being reprecipitated lower down. However, a downward settling of the heavy gold particles in the loose oxidized material may be important. It is concluded from the above line of evidence that residual concentration, due to removal of other constituents, largely accounts for the enrichment of gold in the oxidized zone of the Gibbonsville veins. Near the surface leaching of gold has probably taken place, and leaching above was necessarily followed by precipitation below.

It is thought that similar conditions exist elsewhere in the older gold veins, though not recognized, probably because nowhere else is pyrite

¹ Emmons, W. H., The agency of manganese in the superficial alteration and secondary enrichment of gold deposits in the United States: Bull. Am. Inst. Min. Eng. No. 46, 1910, pp. 767-837.

so important a factor in the ore and because, consequently, nowhere else is the concentration due to its breaking down so pronounced. Indeed it is believed to be this difference in tenor, slight though it is, between the oxidized ore and the primary ore that has given rise to the local opinion that the veins decrease in value with depth—a conclusion which is apparently unfounded, if primary ore alone is considered.

AGE AND GENESIS.

The age of these veins can be placed within rather narrow limits. They are so strikingly similar in their make-up that there is little room to doubt that they date from the same period of mineralization. Some of them are inclosed in late Cretaceous granite; hence they are younger than that intrusion. On the other hand they present the mineral association and physical make-up typical of veins formed at a great depth, probably 4,000 or 5,000 feet. In many places in the Mackinaw and Eureka districts veins have been worked at elevations approximating 7,500 feet, whereas the Eocene erosion surface in their vicinity stands at about 8,500 feet. It follows that the veins were formed while the area was covered by 3,000 or 4,000 feet of material now removed—material that could only have been present prior to the erosion which culminated in the broad planation of the region and the development of the Eocene erosion surface. The veins therefore antedate the later and possibly even the middle part of the period of erosion, which probably occupied the greater part of the Eocene epoch. It is concluded, therefore, that the veins are of late Cretaceous or early Eocene age, probably the former.

The geographic distribution of the veins and the granite and their age relations lead to the conclusion that the veins are genetically related to the granite. Those in the central part of the county are conspicuously coincident in distribution with the contacts of the granite, being either in the granite or in the rocks which it intrudes, whether these are schist, as in the Indian Creek and Eureka districts, or gneiss, as at Mineral Hill. In the Mackinaw district a great outlier of schist within the granite area illustrates the same relation, the Copper King and Mayflower properties being inclosed in schist and the Italian and Haidee in granite. In the Gibbonsville district granite is not exposed, although its occurrence as great batholiths, 10 to 20 miles to the southeast, southwest, and north, suggests that it may underlie the district. At Yellow Jacket it is thought to be present though not exposed (p. 169). Along the Beaverhead Mountains lamprophyre dikes suggest the presence of granite. Thus throughout the area the veins are confined either to the margins of the granite or to areas where there are reasons for thinking that the granite lies at no great depth.

That the granite and the veins are closely related in age, the veins being a little younger, follows from the considerations stated on page 29 and outlined here. If the granite caused the elevation of the area, which by its reduction gave the Eocene surface, and if the veins are not later than the middle stages of that reduction, it follows that the granite and the veins are not far apart in geologic time. As the veins are in places inclosed in granite they are the younger. This age relation and the distribution of veins near the margins of the granite seem to point definitely to a genetic relation between them.

These relations give strong support to the theory of ore deposits that regards many veins as having been formed by solutions given off from an igneous mass, usually after its outer part has solidified. Thus the veins occur around the margins, extending into the mass itself and into the rocks which it intrudes.

SIMILAR DEPOSITS.

Deposits of this age and with similar characteristics are widespread in Idaho, Montana, and eastern Washington, and occur locally in Utah (Mercur) and Colorado (Leadville). In many places they have afforded rich placers, as at Bannock, Alder Gulch, Helena, and Confederate Gulch, in Montana.¹

LEAD-SILVER DEPOSITS.

DISTRIBUTION.

Lead-silver deposits are confined to the southeastern part of the county, from Junction southward to the head of Birch Creek. Within this area four mining districts are recognized—Nicholia to the southeast, Spring Mountain west of it, Texas north of that, and Junction still farther north—in all covering an area about 30 miles long and 20 miles wide. The known deposits are further limited to three localities—(1) a narrow belt along the east face of the Lemhi Range, extending about 10 miles south and 2 miles north of Gilmore; (2) the Nicholia district, about 15 miles farther east, where two claims have been found to contain very productive deposits; and (3) a narrow belt, perhaps 5 miles long, northeast of Leadore. The continuation of this belt northwest of Junction has afforded reasonable encouragement to the prospector, but so far no commercial deposits on it have been opened.

GEOLOGIC RELATIONS.

The area consists of a mountainous country traversed by a broad valley filled deeply with Miocene sediments. The rocks forming the mountains are dolomites, limestones, slates, and quartzites of Paleozoic

¹ Lindgren, Waldemar, The geologic features of the gold production of North America; Trans. Am. Inst. Min. Eng., vol. 33, 1903, pp. 802-804.

age. Cutting them are broad dikes of quartz diorite and related porphyries, and in one and possibly two places small batholithic masses of the same material. In general the older formations dip east in the western part of the area and west in the eastern part.

All known lead-silver deposits in Lemhi County are inclosed in Paleozoic sedimentary rocks; most of them are in close proximity to quartz diorite dikes, though few are in actual contact.

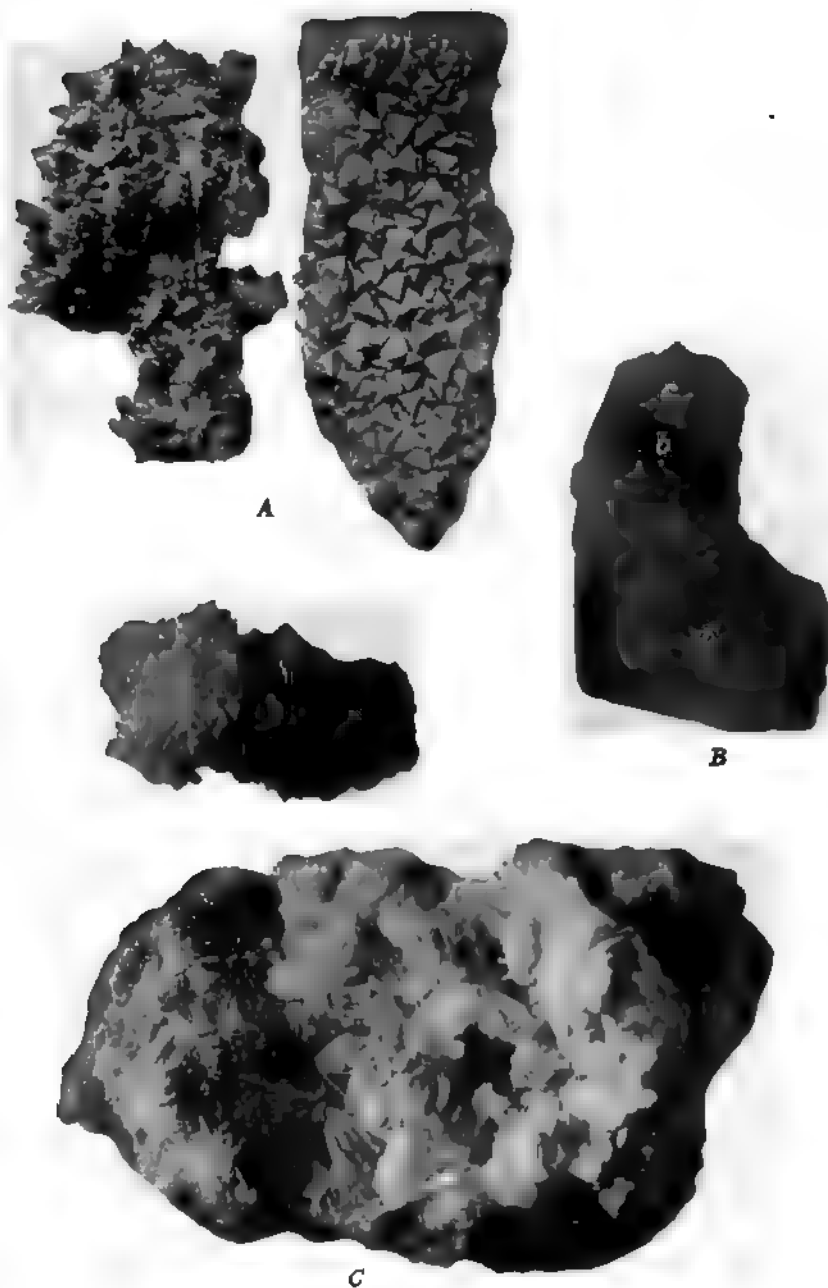
CHARACTER OF DEPOSITS.

The lead-silver deposits are tabular bodies with extensions along bedding and joint planes and numerous swells in the main mass. Figure 10 (p. 101) illustrates the veinlike character of the Pittsburgh-Idaho deposit, and figure 17 (p. 117) illustrates the same relation in the Leadville mine. The Latest Out ore body is also tabular, but many isolated bunches of ore appear in the wall rock near the vein. Figures 14 and 15 (pp. 105, 106) illustrate the outline of two bodies of ore in this deposit. In many places well-defined fissure walls continue even where the ore has ceased, the space being filled by gouge.

ORES.

Mineral character.—The structure of the lead-silver ores is greatly obscured by the advanced degree of oxidation which prevails throughout most of the present workings. The Leadville mine is the only developed property where primary minerals predominate. Here the ore is fine-grained argentiferous galena, remarkably free from gangue but with numerous small patches of intergrown pyrite and with a little chalcopyrite. Arsenic, antimony, and bismuth appear in analyses of the ore, but their mineral combinations are unknown.

In most of the deposits oxidation is almost complete, the ore being a mass of earthy carbonate heavily stained with iron and manganese and commonly having strong suggestion of metallic luster. Probably 80 per cent of the lead-silver ore shipped from the county is composed of minerals resulting from the oxidation and carbonation of galena, pyrite, and zinc blende. Cerusite and iron oxide are by far the most conspicuous minerals in the deposits. Anglesite is common as a narrow band around galena. (See Pl. X, *B.*) Smithsonite occurs as botryoidal linings of small cavities and as stringers along joints. Calamine is rare and appears as small needle-like crystals extending from the sides of vugs otherwise lined by smithsonite. (See Pl. X, *C.*) Manganese oxides are common as stains and dendrites. Pyromorphite is rare, cerargyrite probably very common but in exceedingly small grains, malachite uncommon, and minium very exceptional. From analogy with other lead-silver deposits of



ORE FROM PITTSBURGH-IDAHO MINE.

- A.* Aragonite (on left) and calcite (on right), as developed along open fissures. Natural size. *B.* Galena (*a*) partly altered to cerussite (*c*), anglesite (*b*) is an intermediate phase. 400-foot level. Natural size. *C.* Calamine crystals on drusy base of smithsonite, East vein, between 300 and 400 foot levels. Enlarged 2 diameters.



the State, in all of which iron carbonate is a characteristic gangue mineral, it is possible though not probable that siderite occurs in the primary ore.

The general make-up, tenor, and variations in the ore from place to place are brought out clearly by average analyses derived from smelter returns. The extremes for each item, as well as the average, are given in the following tables:

Average analyses of ore from Pittsburgh-Idaho mine, Texas district.

[25 shipments, ending Sept. 10, 1910; total, 2,275 tons.]

	Gold.	Silver.	Lead.	Copper.	Silica.	Iron.	Zinc.	Sulphur.
	Ounces.	Ounces.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Average.....	0.031	15.29	37.04	.....	20.0	8.4	9.05	0.59
Highest.....	.035	16.70	41.00	.....	23.0	9.6	11.00	.80
Lowest.....	.020	13.40	31.75	.....	16.3	7.3	6.90	.06

Average analyses of ore from Latest Out mine, Texas district.

[14 shipments; total, 962 tons.]

	Gold.	Silver.	Lead.	Copper.	Insoluble.	Iron.	Zinc.	Sulphur.
	Ounces.	Ounces.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Average.....	0.0285	18.09	34.25	0.34	25.31	9.23	5.48	0.86
Highest.....	.03	21.5	41.13	.48	27.7	10.8	6.9	1.95
Lowest.....	.0225	14.7	29.65	.....	19.75	7.35	4.6	.6

Smelter analyses of ore from Spring Mountain district.

[On lots varying from 20 to 75 tons.]

Property.	Gold.	Silver.	Lead.	Iron.	Silica.	Lime.	Remarks.
	Ounces.	Ounces.	Per ct.	Per ct.	Per ct.	Per ct.	
Lemhi Union.....	12.2	38.7	16	10.4	4.3	Average of 7 analyses on lots of about 50 tons each. Two contained 10.8 per cent barium. Contained 3 per cent of copper. 160 tons in lot. Four or five tons in lot. Sample. Sample.
Do.....	5.08	19.8	13.71	20.6	3.84	
Iron Mask.....	9.5	19.9	10.25	49.9	3.07	
Teddy and Eliza-beth.	0.02	11	19.5	10.1	21.2	9.97	
Russell.....	12.1	15.2	18.16	27.6	5.63	
Galena.....	2.8	20.1	25.08	13	9.6	
Red Warrior.....	13	53.1	.....	.....	.....
Do.....	5	23	Sample.

Smelter analyses of ore from Leadville mine, Junction district.

	Gold.	Silver.	Lead.	Copper.	Insol- uble.	Zinc.	Sul- phur.	Iron.	Arsenic, antimony, and bismuth, not separated.
		Ounces.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per cent.
No. 1 shoot.....	Trace.	35.0	56.5	0.2	16.0	.....	9.8	2.8	.....
No. 2 shoot.....	Trace.	28.8	54.5	.2	15.0	1.0	11.0	2.0	9.7

An inspection of the first two tables shows that a very small percentage of the total metallic content is in a sulphur-bearing form; that is, is either sulphide, sulphate, or sulphantimonite. It is obvious from their general appearance that the ores are largely carbonate, but just what percentage of the lead is in this form is not readily determinable. On the assumption, however, that all the sulphur is in combination with the lead as galena, since that mineral has a higher percentage of lead than any of the others, it appears that, as a minimum, 90 per cent of the lead in the ore from the Pittsburgh-Idaho mine and 84 per cent of that from the Latest Out mine is in a form other than the sulphide, sulphate, or sulphantimonite. From the absence of other minerals in conspicuous amounts it is concluded that most of this, or 80 to 90 per cent of the lead in these ores, occurs as lead carbonate.

As in the third set of analyses sulphur is not given, calcium oxide, though unsatisfactory, is the only basis for determining the extent of oxidation. Only in the Lemhi Union and Iron Mask properties is the amount of calcium less than would be expected were the lead all in the form of carbonate. The occurrence of barium, probably entirely as barite, in some of the ores from the Teddy and Elizabeth mines is interesting in that they are the only places where barite was noted in the lead-silver deposits.

The amount of sulphur contained in the Leadville ore (fourth set of analyses) indicates that it is made up primarily of sulphide minerals.

In all the ores, copper and gold are negligible. Lead constitutes about one-third of the total vein content. There is usually about one-half ounce of silver to each unit of lead.

Oxidation and ground-water level.—Exploration of the lead-silver deposits has been well above ground-water level. In the Texas district ground-water level, based on the elevation of springs (p. 97), is thought to be from 6,800 to 7,000 feet above sea level east of the quartz diorite dikes and somewhat higher west of them. In the Spring Mountain district the level is in steps determined by low points in the quartz diorite dikes which serve as submerged dams (p. 85). In the Junction district, west of the dikes, the level of Lemhi River is probably the determining factor; east of the dikes the low points in the dikes themselves control.

Oxidation and carbonation will probably be found to be almost coextensive with the depth of ground-water level. Thus it will vary up to possibly 1,000 feet below the surface in known deposits, this maximum being probable in the Pittsburgh-Idaho mine.

Relation of ores to ground-water level.—A conspicuous feature of the oxidized zone is the loose make-up of the ore. Small vugs lined with secondary minerals are common, and a general incoherency of the mass is noticeable everywhere. In contrast to this condition the

primary ore, as seen here and there in protected spots, especially at the Leadville mine, has very little pore space. The alteration of galena to cerusite involves an increase of 28 per cent in volume, of pyrite to limonite an increase of 2 per cent in volume, and of sphalerite to smithsonite an increase of 22 per cent. It appears, therefore, that the minerals occupying the oxidized zone represent far more volume per unit of metal than those from which they were derived. As they are more loosely assembled than were the primary minerals, it follows either that the space occupied by them has been enlarged or that there has been important leaching of the vein material. If the space occupied by the ore has been materially enlarged during the general period of oxidation, it would seem that the ore along its contact with the walls should be more loosely assembled than that in the central portion of the vein, a relation which does not appear to exist. In many places also the fissure walls which bound the ore continue beyond the limits of the ore shoot, but without noticeably converging. From these observations it is concluded that although solution of the walls may have accompanied oxidation it has not been sufficiently extensive to account both for the increased porosity of the ore and for the increased volume due to changes in its mineral constitution. There seems little room to doubt that there has been a pronounced leaching of the vein material, and it remains to determine the order, and as nearly as possible the ratio, in which the metals have been leached, so as to form an idea of what changes may be expected in the relative proportions of metal content when primary ore is reached.

Experiments have shown that under conditions approximating those of nature, sphalerite in the presence of pyrite is oxidized six times as readily as galena under the same conditions.¹ Pyrite is less susceptible than sphalerite when both are in the same deposit. Of the resulting products of this oxidation the lead is by far the most stable and zinc the most unstable, as shown by the relative solubility of the sulphates involved. The lead sulphate although not absolutely insoluble is relatively so; and the sulphate of iron although very soluble is three to four times less so than that of zinc. The zinc salt is so very readily taken into solution that 161 parts of it may be dissolved in 100 parts of water at 20° C.² These values can not be assumed as absolute in the oxidation of a vein where conditions are variable and in some respects unknown, but they represent a general order which seems susceptible of practical application.

As the alterations represented in the deposits necessitate an increase of volume per unit of metal contained and as the deposits are more

¹ Buehler, H. A., and Gottschalk, V. H., Oxidation of sulphides: *Econ. Geology*, vol. 5, 1910, pp. 30-31.

² Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 181.

COPPER DEPOSITS.

lead-silver deposits, suggest that these are the same age as the gold veins, and hence postgranite; that is, that they are late Cretaceous or early Eocene. That they are later than the granite is further indicated by their similarity (save in the siderite gangue, which is not recognized in Lemhi County) to the deposits in the Wood River district, which are later than the granite.¹

If the lead-silver deposits were formed during the same period of mineralization as the late Cretaceous or early Eocene gold veins, as seems altogether probable, it is reasonable to think that both were produced by the same agencies, and, as the gold veins are genetically related to the granite intrusion (p. 62), to assign the lead-silver deposits to that source. Quartz diorite dikes are so common in the vicinity of the latter deposits that a relation between the two is strongly suggested. If a relation exists, however, the two are different expressions of the same general phenomena, as the veins are older than at least some of the dikes. The dikes are pretty surely differentiations from the granite, for in the Wood River district the two are gradational,² hence another suggestion that the lead-silver deposits are related to the granite.

COPPER DEPOSITS

DISTRIBUTION.

Copper deposits are distributed widely in Lemhi County, although their commercial importance has not yet been demonstrated. On Spring Mountain a large deposit of low-grade ore occurs along a zone parallel to the lead-silver veins, and extends for miles from them. Northward, near the head of the Lemhi River, is the Queen mine, the only property in the county where good copper ore has been located. Other properties are located in the Snake River Valley on Diott Creek. In the mountains south of the Snake River, near Salmon, a considerable deposit of Salmon copper is found, and to the west, in the Lemhi district, 29 patented claims

are

• sedimentary formations;
limestone and dolomites,
sandstone, and slates. Either
of these is the source of the deposits
of copper.

• Siderite
• Magnetite
• Hematite

CHARACTER OF THE DEPOSITS.

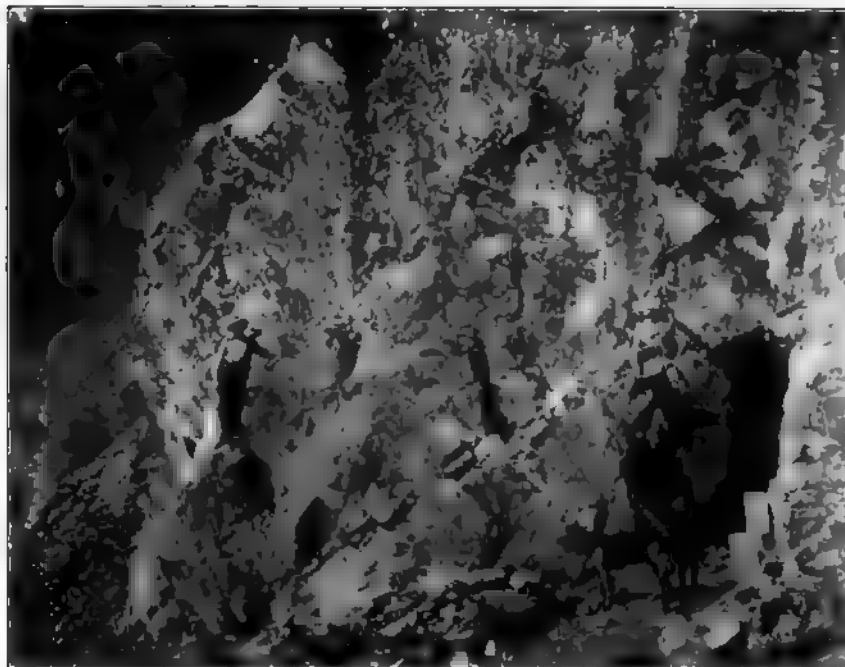
The deposits vary in form from fissure veins (Copper Queen) to impregnations in schist (in places on Torney group) and contact-metamorphic deposits (Bruce estate) with irregular mineralization along sheeted zones as the most common type. The Copper King deposit, which represents the last named, consists of an irregular vein about 2 feet wide, accompanied by very many parallel stringers separated from each other and the main vein by mineralized wall-rock. The entire mineralized zone is about 40 feet wide. In the Brown Bear shaft, Blackbird district, a similar deposit is said to be more than 100 feet wide. Each of these is opened for 400 or 500 feet and is shown to be fairly persistent, though low grade.

ORES.

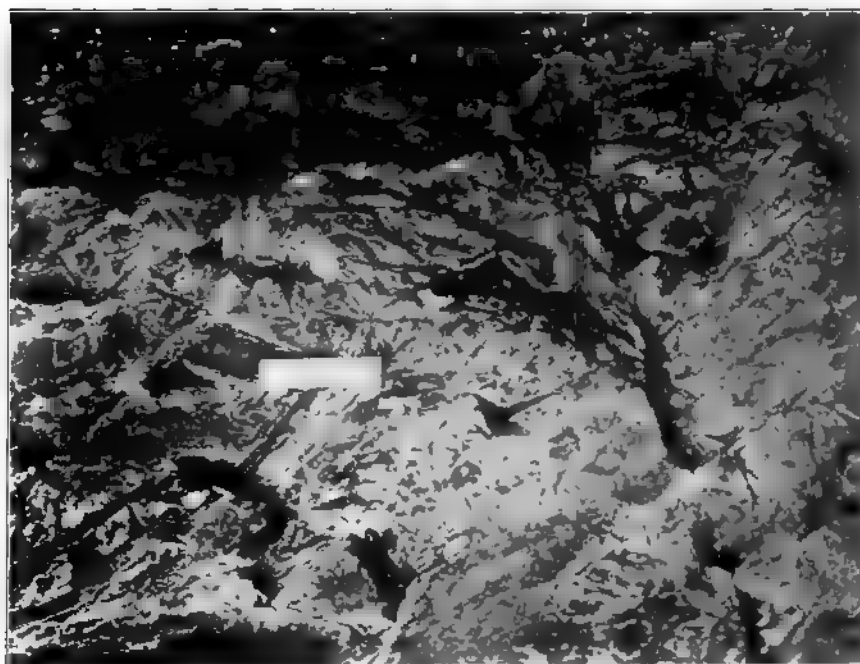
The characteristic copper ore encountered in the county is coarse quartz studded and stained with the alteration products of chalcopryrite. Of these, bornite and malachite are most abundant, the former being the predominant mineral at the Copper Queen mine. Chalcocite is common in some properties (Copper King). In general, azurite, cuprite, chrysocolla, covellite, and melaconite are decreasingly abundant in the order named. Although chalcopryrite appears to be the source of most of the minerals, it is not conspicuous within the limits of present development. It occurs as cores surrounded by bornite, covellite, and rarely by malachite, and as irregular bunches, streaks, or isolated crystals, which, by reason of local conditions, have not been oxidized. Gold is associated with the copper in all of the deposits, as is also pyrite.

AGE AND GENESIS.

There seems to be every gradation between the pyritiferous gold veins and the auriferous copper deposits. The Carmen Creek mine is classed with the gold veins, although it might almost equally well be classed with the copper deposits. The Copper Queen mine is considered a copper property, but it might with equal justification be listed with the gold properties. It is further noteworthy that chalcopryrite is present in all the late Cretaceous gold veins and pyrite in all the copper deposits. As the gold and copper deposits possess like characteristics except for their relative content of pyrite and chalcopryrite and as the above stated relations exist between these it is concluded that the deposits are of the same age and genesis. In the copper deposits chalcopryrite simply replaces pyrite, hence the discussion as to the age and genesis of the gold-bearing veins (see p. 62) applies to copper-bearing veins and leads to the conclusion that they are late Cretaceous or early Eocene and are genetically related to the late Cretaceous granite intrusion.



A.



B.

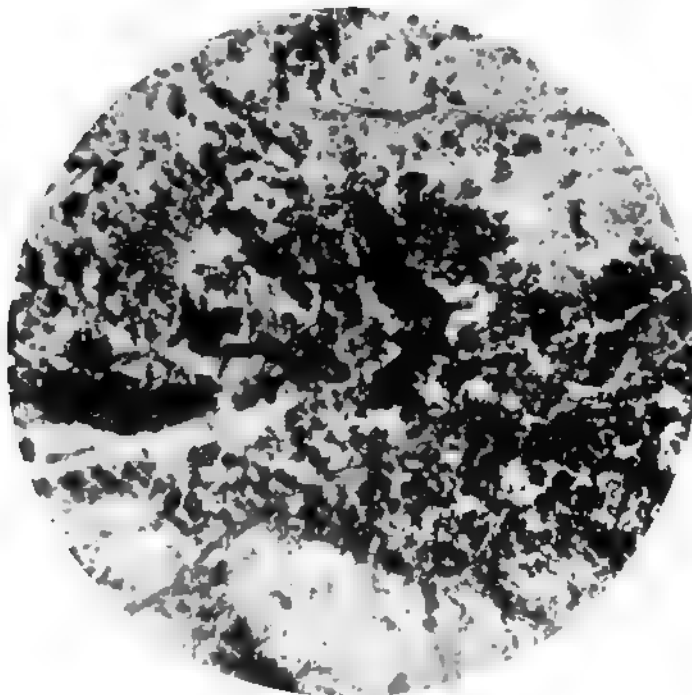
COBALT-NICKEL LODGE, EAST END OF BELIEL GROUP, BLACKBIRD DISTRICT

A. Outcrop of lode. B. Efflorescence of erythrite on surface of lode.



A. COBALT ORE FROM BROOKLYN CLAIM, BLACKBIRD DISTRICT

Mineralization has taken place along fractures in a fine-grained quartzite. Enlarged 35 diameters; nicols crossed.



B. COBALTITE (?) REPLACING BIOTITE AND QUARTZ IN A BIOTITIC QUARTZITE, BLACKBIRD DISTRICT

Very small grains bunched in poorly defined lenticular areas. Enlarged 35 diameters; nicols crossed.

COBALT-NICKEL DEPOSITS.

DISTRIBUTION.

The known cobalt-nickel deposits of the area are confined to the Blackbird district in the west-central part of the county. The most promising properties are situated near the junction of north and south forks of Blackbird Creek. Thence northward, prospects are located for 5 to 6 miles—the most northern ones being situated about the head of Little Deer Creek, a small stream which flows north into Big Creek. (See Pl. XI, *A*, *B*.)

GEOLOGIC RELATIONS.

The deposits are situated in an area of Algonkian schists and quartzites, cut by diabase and lamprophyre (minette) dikes. That a portion of the great granite batholith underlies part of the area is suggested by its occurrence in Big Creek valley, and by the extensive metamorphism of the Algonkian sedimentary rocks. Biotite is the most abundant mineral developed, although locally garnet and chiastolite crystals were noted. In general the Algonkian beds strike N. 60°–80° E. and dip 40°–60° NW. Crossing their strike is a strong joint system which strikes N. 10°–40° W. and dips 80° SW.

Gabbro dikes as much as 100 feet wide parallel the mineralized belt in north-south direction. They are blue-black holocrystalline rocks consisting of hornblende, diopside, plagioclase, and biotite, with accessory pyrrhotite, pyrite, titanite, and apatite. Minette dikes appear to follow both the strike of the formations and the cross joints. They are fine-grained dark-gray resinous rocks consisting of biotite and orthoclase accompanied by subordinate amounts of plagioclase and hornblende.

CHARACTER OF THE DEPOSITS.

Most of the deposits are lenslike bodies, although a few assume the broadly tabular form of veins. (See Pl. XII, *A*.) Again, they form bunches or occur as disseminations along certain favored zones. In one place (Hawkeye group) irregular bunches of nickeliferous pyrrhotite up to 4 or 5 inches in diameter are sparsely scattered through a gabbro dike. This pyrrhotite may be a direct segregation from the gabbro magma, but the fractured condition of the specimens secured precludes definite determination. Elsewhere deposits are primarily of replacement origin, the fine-grained metallic minerals being distributed in bunches, lenses, and disseminations along ill-defined zones in the schist or quartzite. (See Pl. XII, *B*.) The ore minerals are everywhere accompanied by quartz, which in places is coarse and includes them as gangue but elsewhere is exceedingly fine-grained and is intergrown with them.

ORES.

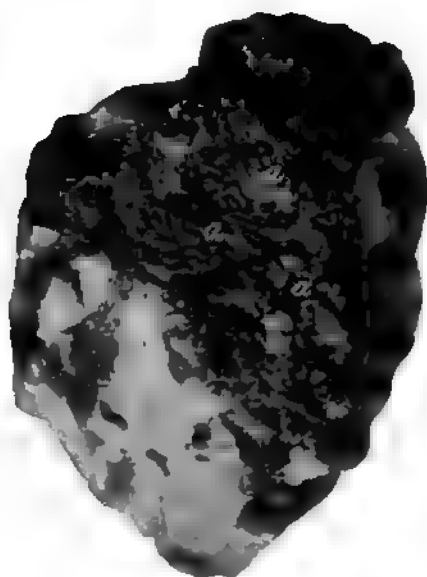
Most of the outcrops of the cobalt-nickel deposits are stained by erythrite, the pink to pearl-gray cobalt blossom, and annabergite, the pale apple-green nickel compound. In addition, malachite, limonite, and pyrolusite are present in many outcrops. The primary cobalt and nickel minerals are difficult to recognize, owing to their occurrence in grains of microscopic size which are invariably intergrown with something else. At least two cobalt minerals in the area are probably primary: The one is a reddish-gray mineral (Gray Eagle claim) which occurs in very small grains replacing biotite and quartz in a garnetiferous biotitic quartzite; the other is a steel-gray mineral, which occurs as minute grains distributed through the quartzitic rock on the west end of the Beliel group. The former is probably cobaltite and the latter is possibly smaltite. Most of the nickel of the area is thought to be in the form of nickeliferous pyrrhotite, a specimen of this mineral from the Togo claim yielding 0.8 per cent nickel. A pale copper-red mineral, rarely seen in the Togo ores, may be niccolite.

The properties are too little developed to establish the tenor of the ores. A sample representing 20 feet across the ledge, as exposed by tunnel on the west end of the Beliel group, averaged a fraction less than 2 per cent cobalt. The east end of this property afforded 2 per cent of nickel and less than 1 per cent of cobalt. As now developed this seems to be the best cobalt-nickel deposit.

AGE AND GENESIS.

Within Lemhi County it is impossible to differentiate the times of deposition of the cobalt-nickel, copper, and gold deposits. The relations indicate that they all belong to the same general period of mineralization, and as the gold veins are assigned to the late Cretaceous or early Eocene and are genetically related to the great granite mass, the other deposits also are credited to the same age and origin. The coextent of the gabbro dikes and the cobalt-nickel deposits, and the inclusion of nickeliferous pyrrhotite in the gabbro in a manner to suggest its derivation from the gabbro magma, points to a close relation between the two. This, however, is probably a minor though an important feature in the broader relation between the granite batholith and the deposits.

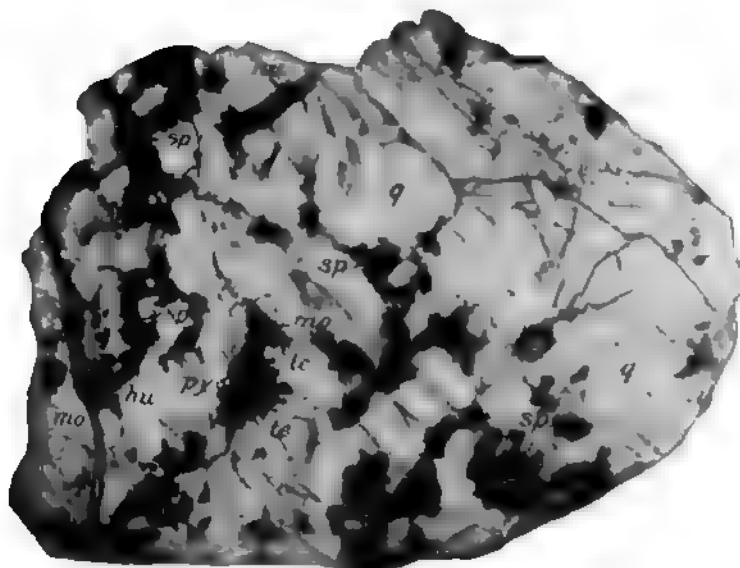
The cobalt-nickel deposits, therefore, are thought to be of late Cretaceous or early Eocene age and to be genetically related to the great granite intrusion. They are closely associated with gabbro dikes, which are probably differentiations from the granite magma.



A



B



C

ORES AND MINERALS FROM BLUE WING DISTRICT

.1 Rosettes of manganese oxide (*u*) developed along fractures in the vein quartz. Natural size. *B*. Siderite occurring locally along fractures in ore. Enlarged 3 diameters. *C*. Tungsten ore from Idaho Tungsten Co.'s creek tunnel; *q*, quartz; *hu*, hübnerite, *sp*, sphalerite (resembles hübnerite but gives white instead of brown streak), *py*, pyrite, *tr*, tetrahedrite, *mo*, molybdenite. Natural size.



TUNGSTEN DEPOSITS.**DISTRIBUTION.**

Tungsten occurs in the Blue Wing district, situated 20 miles southwest of Leadore. This district includes a township or so along Patterson Creek, a northern tributary to Pahsimeroi River near its head. Gold locations were made in the district as early as 1881, but tungsten was not recognized until 1903. Since then it has attracted some attention, and recently active operations have been begun. A 50-ton concentrating mill is now running, and the concentrates will be hauled to Leadore as soon as the road now in course of construction is completed.

CHARACTER OF THE DEPOSITS.

The deposits are fissure veins along the axis of a pronounced anticline which strikes N. 30° to 40° W. Quartzitic slates and schists of Algonkian age inclose the deposits. No igneous rock crops out in the immediate vicinity, although quartz diorite is known to occur at several places along the Lemhi Range.

ORES.

The ore consists of coarsely crystalline quartz, which occurs in veins varying in width from stringers up to 4 feet and rarely up to 12 feet. Irregularly scattered through the quartz are small bunches of sphalerite, bladed crystals of hübnerite, small areas of tetrahedrite, and specks of molybdenite and galena. (See Pl. XIII, C.) Secondary to these are limonite, malachite, azurite, cerargyrite, bornite, chalcocite, and cuprite. Scheelite, probably also secondary, was noted as pale-yellow druses lining a small cavity and as specks in the loose granular filling of some crevices. Manganese oxides (Pl. XIII, A) are secondary, although their derivation was not recognized. Molybdenite occurs bunched along fractures and in the interstices of brecciated quartz in a manner to suggest its secondary origin. This mineral, however, because of its graphite-like character, is likely to be squeezed out of its gangue if that is crushed and to accumulate in fractures and interstices. Molybdenite is not known to be a secondary mineral and it is thought that the above explanation accounts for its occurrence in this deposit. The paragenesis of the several primary minerals is discussed elsewhere (p. 111).

GENESIS.

The tungsten veins can be traced up the canyon side almost, if not quite, to the level of the Eocene surface; hence they antedate its formation. As only two periods of mineralization have been recognized in this part of Idaho and the later is post-Eocene, these

deposits are assigned to the earlier, which is of late Cretaceous or early Eocene age. They are also believed to be genetically related to the great granitic intrusion which gave rise to the older period of mineralization. Along the Lemhi Range the granitic activity is represented by numerous dikes and a few bosses of quartz diorite. The tungsten deposits are thought to be a phase of this activity.

TIN DEPOSITS.

Placer tin has been found along Panther Creek near its junction with Moyer Creek and along Silver Creek below Rabbitfoot. The latter deposit has been prospected sufficiently to show the absence of tin in commercial quantity, but the former is inadequately developed.

The metal occurs as the oxide, cassiterite, and is of the variety commonly known as stream tin. Individual pieces vary in size from small rounded grains to pebbles a half inch or more in diameter. The tin pebbles, as they occur on Panther Creek, are sparsely distributed through the lower portion of a bed of gravels which varies from 4 to 20 feet in thickness. This deposit has not been thoroughly prospected and little is known of its merits.

The source of the tin is not known, although it is safe to assume that it is concentrated from primary deposits formed during the older period of mineralization.

MINERALOGY OF LEMHI COUNTY ORES.

GENERAL FEATURES.

Sixty-three mineral species are recognized in the ores of Lemhi County. Seven of these (actinolite, chlorite, epidote, forsterite, garnet, mizzonite, and sericite) are not strictly ore minerals, but their association with the ores where they are found is so intimate that they are included in the following list. It is concluded (pp. 56, 62-63) that the deposits of the county were formed during two general periods of mineralization, the older being late Cretaceous or early Eocene, and the younger late Miocene or early Pliocene. It is noteworthy that most of the minerals of the area appear in most of the older deposits. Pyrite, chalcopyrite, galena, and sphalerite, although varying greatly in relative amount from place to place, are omnipresent, and they are all included in coarsely crystallized quartz. The younger deposits are characterized by fine-grained quartz, adularia, sericite, opal, and chalcedony.

ORE MINERALS.

Any list of minerals based on reconnaissance studies is pretty sure to be incomplete, and the considerable variety noted in Lemhi County suggests that many others are present. In the following list the

known species are arranged in alphabetic order, and each is accompanied by brief notes on its occurrence.

Actinolite.—The metamorphic silicate actinolite is developed in schists included in the deposits on Carmen Creek. It is probably also present in the cobalt-nickel ores of the Blackbird district.

Adularia.—Vein feldspar (adularia) is very abundant in the ores from the Gravel Range district and is probably present in the Parker Mountain district. It occurs in minute crystals of microscopic size and generally of rhombic outline. A few crystals are included in quartz grains, but mostly they are intergrown with them.

Anglesite.—Although lead sulphate (anglesite) was seen only in the Texas and Junction districts, it is probably present elsewhere. It occurs as a transition form in the alteration of galena to cerusite but is nowhere abundant.

Annabergite.—Nickel bloom (annabergite) is conspicuous in the outcrops of nickel deposits in the Blackbird district. It occurs as crusts and stains of pale apple-green color.

Argentite.—Silver sulphide (argentite) was noted in small amounts in the Pittsburgh-Idaho mine of the Texas district.

Arsenopyrite.—Iron sulpharsenide (arsenopyrite) occurs intergrown with quartz in some of the veins at Mineral Hill and also in the older deposits at Blackbird.

Asbolite.—Earthy cobalt (asbolite) is found along a few crevices in the cobalt deposits of the Blackbird district.

Azurite.—The blue carbonate of copper, azurite, although nowhere as abundant as malachite, was noted in most of the districts of the county. It occurs in the oxidized portion of those veins which bear copper minerals.

Barite.—Barium sulphate or heavy spar (barite) is intergrown with quartz in one of the gold veins at Mineral Hill and occurs also as a gangue mineral in two deposits of lead-silver ore at Spring Mountain. It is nowhere abundant.

Biotite.—Biotite is developed as beautiful rosettes in some of the cobalt-nickel ores (Togo claim especially).

Bornite.—Bornite occurs abundantly in the deposits along the Continental Divide and free gold commonly accompanies it. In the Copper Queen mine it constitutes a copper ore. It was noted in small amounts in many other parts of the county.

Braunite.—The oxide of manganese (braunite) occurs in the ores of the Kittie Burton mine, Indian Creek district, as small brownish-black granular masses and scattered minute pyramidal crystals.

Calamine.—Hydrated zinc silicate (calamine) occurs in beautiful needle crystals and sheaf-like aggregates, protruding from the walls of small cavities in the ores of the lead-silver deposits. The crystals are usually set on a base of smithsonite.

Calcite.—Lime carbonate (calcite) is widespread in the area, occurring in subordinate amounts in the gangue of most veins.

Cassiterite.—Stream tin occurs along Panther Creek near its junction with Moyer Creek and is also reported from Silver Creek. In neither place, however, have deposits of commercial extent been demonstrated.

Cerargyrite.—Horn silver (cerargyrite) occurs in very small particles in the oxidized portions of the lead-silver deposits, being one of the products in the breaking down of argentiferous galena. It was also noted as a secondary product at the Carmen Creek mine and in the Blue Wing district.

Cerussite.—Lead carbonate (cerussite) is by far the most important lead mineral mined in Lemhi County. It constitutes the principal ore in the Nicholia, Spring Mountain, and Texas districts.

Chalcedony.—Chalcedony was noted only in the ores at Parker Mountain, although it is probably present in the other late Tertiary veins.

Chalcocite.—Copper glance (chalcocite), though nowhere abundant, can generally be found a short distance below the surface in the copper-bearing deposits.

Chalcopyrite.—Chalcopyrite is one of the persistent minerals of the area, occurring in all the districts and in most of the deposits. In places it is associated with gold, but commonly is an inconspicuous companion of pyrite. It occurs in very subordinate amounts in the lead-silver deposits.

Chlorite.—Chlorite is developed in many fragments of schist inclosed in the vein filling. It appears in this relation in the Eureka and Blackbird districts.

Cobaltite.—A silver-white cobalt mineral inclined to red occurs in grains of microscopic size in the ores of the Blackbird district. It is probably cobaltite.

Copper.—Native copper occurs as films along some of the fractures of oxidized ores in the Indian Creek district. It was not noted elsewhere.

Covellite.—The copper sulphide covellite was noted in a specimen from the Blackbird district. It occurs as beautiful indigo-blue crusts surrounding cores of chalcopyrite, which in turn are surrounded by iron oxide.

Chrysocolla.—Copper silicate (chrysocolla) was noted as a secondary mineral in the Copper King vein.

Cuprite.—Red copper oxide (cuprite) is found in massive and fine-grained forms in a few parts of the Copper Queen and Copper King mines and in the Patterson Creek district.

Epidote.—The complex aluminum silicate epidote occurs at the Copper King mine and at the Carmen Creek property in small green *prismatic* crystals in fragments of schist inclosed in the veins.

Erythrite.—Cobalt bloom (erythrite) occurs as an earthy incrustation of pink and pearl-gray color on the outcrops of cobalt deposits in the Blackbird district. In places, as on the Beliel group, this mineral is so abundant on the faces of cliffs that it can be seen for half a mile or more.

Forsterite.—The magnesium-rich olivine forsterite was noted in a specimen of metamorphosed limestone which occurs in connection with galena along the contact with the diorite dike in Dry Gulch, Spring Mountain district. It is developed in dolomitic limestone.

Galena.—Galena is widespread in the area, occurring in all the deposits except those of late Tertiary age. Although it is the source of the minerals which constitute the ore in most of the lead-silver properties, it is worked only in the Junction district. It occurs both in coarse crystals and fine-grained aggregates, steel galena.

Garnet.—Garnet occurs at several places in the schists of the area, but its association with mineral deposits was noted in only a few localities. One of these is at Spring Mountain, where it is associated with the forsterite, and the other is in the copper deposits of the Copper King mine, where it seems to be especially developed in proximity to the vein.

Gold.—Native gold is widespread in the deposits of Lemhi County, small amounts of it occurring even in the lead-silver veins. In the Tertiary veins it is generally very fine grained, but in many of the older deposits it is sufficiently coarse to be seen readily with the unaided eye. Workable placers have resulted only from the older veins.

Hübnerite.—Manganese-rich tungstate (hübnerite) appears as long-bladed crystals and irregular patches in the quartz of the Blue Wing district. It contains 2.01 per cent ferrous oxide, which indicates that about 21.4 per cent of manganous oxide is present. It forms an ore of tungsten.

Iron oxide.—Iron oxide is widespread in the oxidized zone of all the deposits in the district.

Linnæite.—A steel-gray cobalt mineral, which weathers to a reddish tinge, occurs in grains of microscopic size in the cobalt ores of the Blackbird district. Although not definitely determined it is possible that this mineral is linnæite.

Magnetite.—Magnetic iron appears in connection with the ores on Carmen Creek and in some of the veins in the Mineral Hill, Mackinaw, and Eureka districts. It is developed extensively in the copper deposit (Bruce estate) on Spring Mountain.

Malachite.—The green copper carbonate (malachite) is present in most of the deposits of the county. It is only abundant, however, in connection with the copper lodes.

Manganese oxide.—Manganese oxide is coextensive with iron oxide. In places in the lead-silver deposits it is very conspicuous.

Marcasite.—Beautiful spherical nodules of marcasite, up to 1½ inches in diameter, were secured from the Tertiary beds a mile south of Salmon. The inclosing rock is loosely cemented clay sandstone.

Melaconite.—A little of the black copper oxide (melaconite) occurs in the oxidized ores of Copper King mine.

Minium.—Minium was noted in a very few places as a bright-red powder of greasy luster, partly filling little cavities near the surface of the deposit in the Pittsburgh-Idaho mine.

Mizzonite.—The variety of scapolite known as mizzonite appears in one of the slides from the Yellow Jacket district. It occurs in poikilitic areas, including considerable amounts of hornblende.

Molybdenite.—Molybdenum sulphide was noted as films along fractures and as minute scales and grains intergrown with the primary minerals in the tungsten deposits of the Blue Wing district.

Niccolite.—A pale copper-red mineral with dark tarnish occurs in small, indistinct crystals in the ore of the Togo claim, Blackbird district. It is possible that this mineral is niccolite.

Opal.—Opal occurs as linings of microscopic cavities in the Parker Mountain ore. Properties have been located for the exploitation of opal in the eastern part of the Gravel Range district, where the mineral occurs as linings in the vesicles of rhyolite flows. It has not been found in commercial quantities.

Pyrrhotite.—Pyrrhotite is intergrown with quartz in the Kitty Burton vein, Indian Creek district. It is also conspicuous in the Blackbird district, where much of it is nickeliferous. It occurs intergrown with quartz and possibly as a segregation in diabase.

Proustite.—Silver sulpharsenite (proustite) was seen as small red crusts on specimens from Carmen Creek. It is also said to have been found occasionally in the oxidized ores of the Texas and Spring Mountain districts.

Pyrite.—Pyrite appears in all the deposits of the county. In many of the gold veins it is auriferous.

Pyrrargyrite.—Thin films and fibers of the steel-gray silver mineral pyrrargyrite have been found occasionally in the Junction district.

Pyrolusite.—Pyrolusite, worthy of special mention because of its beautiful dendritic forms, is abundant in many places along fractures and bedding planes in limestone adjacent to the lead-silver deposits.

Pyromorphite.—Short, deeply striated hexagonal prisms of pyromorphite have been secured from the ores of the Texas district. It is, however, one of the rarer minerals of the deposits.

Quartz.—Quartz is widespread in the county.

Rhodochrosite.—Rhodochrosite is meagerly developed in the Kitty Burton vein, Indian Creek district. A beautiful specimen from the Blackbird district was examined; its mode of occurrence is not known.

Scheelite.—Calcium tungstate (scheelite) occurs in the Blue Wing district as thin crusts and specks of pale yellow to white, lining open spaces in the coarse quartz gangue.

Selenide of gold or silver.—A strong trace of selenium, which probably occurs as a selenide of gold or silver, perhaps both, was found in the ores from the Monument mine, Gravel Range district. Its source is probably a blue-black mineral which occurs in scattered and bunched grains of microscopic size. The similarity of these grains to others noted in the Parker Mountain ores suggests that in them also selenium may be present.

Sericite.—Fibrous white mica (sericite) is probably widespread in the area, although it was noted only in specimens from the Indian Creek, Mineral Hill, Mackinaw, and Parker Mountain districts. In the latter district it occurs both in the quartz and in the wall rock adjacent thereto. In the quartz it is probably, in part at least, derived from adularia. It invariably occurs as foils and shreds of microscopic size.

Siderite.—Iron carbonate (siderite) appears in small amounts in many of the lead-silver deposits. Specimens were also noted from the Blackbird and Blue Wing districts. (See Pl. XIII, B, p. 72.)

Silver.—Native silver, though apparently very rare, has been found in some of the ores of the Texas district. It is also reported from the Gold Flint property of the Mackinaw district.

Smaltite.—A cobalt arsenide, possibly smaltite, occurs in the Blackbird district, in fine grains of microscopic size, as a replacement in quartzite and schist. It is perhaps the most abundant cobalt mineral in the district.

Smithsonite.—Zinc carbonate (smithsonite) is present, though in few places abundant, in the several lead-silver deposits of the area.

Specularite.—Beautiful tabular crystals of specular iron are present in some of the veins of the Blackbird district. Specularite was also noted in the Mackinaw district and as a micaceous replacement in dolomite in the Blue Wing district.

Sphalerite.—Sphalerite is widespread in the several districts of the area, although nowhere in sufficient amount to constitute an ore of zinc. As much as 10 per cent zinc, probably mostly from secondary minerals derived from sphalerite, appears in some of the lead-silver deposits.

Sulphur.—Native sulphur, partly filling small cavities due to the removal of pyrite, was noted in one of the Clipper Bullion veins, Mineral Hill district.

Tetrahedrite.—Gray copper (tetrahedrite) carrying 1.9 per cent silver occurs as irregular patches and specks in the ores of the Blue Wing district.

OXIDATION AND GROUND-WATER LEVEL.

The depth of oxidation is one of the most vital questions in the exploitation of the gold veins of Lemhi County, for the unoxidized ores yield only a small percentage of their gold to amalgamation, and many of them contain sufficient copper to interfere seriously with cyanide treatment. Most of the properties were temporarily abandoned when primary ores were reached, but a few, especially those at Gibbonsville and Ulysses, have continued to be operated.

In most parts of the county oxidation is almost complete for 100 to 150 feet below the surface, but in the lead-silver areas it extends locally much deeper, in places possibly a thousand feet deeper. With few exceptions (notably in the Leadville mine) oxidation reaches to or below ground-water level. Where it extends below water level, however, the deposits are well above an adjacent valley which determines the low points in the water table, for it can not be assumed that because water will stand in a shaft on a hillside circulation toward the valley (in many instances active flow) does not take place. A shaft thus situated may serve as a secondary low point in the water table and may contain water, but, structural relations being normal, there will be flow from it to low points in the water table. Therefore, as descending ground water is an active oxidizing agent, deposits situated on a hillside can not be considered abnormal even if oxidation extends well below the level at which water stands in adjacent shafts. In Lemhi County, Gibbonsville (p. 13) offers the best illustrations of this relation.

AGE AND GENESIS OF THE ORES BY GROUPS.**SUPERFICIAL DEPOSITS.**

The superficial deposits of Lemhi County consist entirely of gold placers. In age they are Miocene (part of those on Kirtley Creek), Pliocene (Moose Creek, Bohannon Bar, Kirtley Creek, Leesburg Basin), post-Pleistocene (Phelan Creek, part of Leesburg Basin); and very recent (Haidee mine). Of the several groups those of Pliocene age have afforded nearly all the production. The sources of all the commercial gold placers are the late Cretaceous gold quartz veins or stringers. Thus, at Leesburg the gold has come from known deposits on the west, and at Moose Creek from veinlets and lenses in the granite on the east. Above Bohannon Bar no veins have been found, but on Kirtley Creek lode deposits are worked. The late Tertiary gold veins at Rabbitfoot have yielded placers, but the production has been meager.

INCLOSED DEPOSITS.

LATE TERTIARY GOLD VEINS.

Late Tertiary veins in the county are included in Miocene rhyolites or in rocks once capped by them. On the other hand, deep valleys, glaciated in their upper parts, cross the lodes at Myers Cove and Parker Mountain. Thus the veins are late Miocene or early Pliocene.

The wall rock of the deposits shows considerable alteration, sericitization and silicification being the important processes. Within the veins adularia is remarkably abundant locally, pyrite is generally present, and selenium, probably as a selenide, is known to occur. It is concluded, therefore, that the veins were formed by hot ascending solutions which deposited along the main channels and permeated the adjacent rocks. These solutions were rich in silica, aluminum, potash, and contained iron, sulphur, and appreciable amounts of gold, silver, and selenium.

The confinement of this type of veins to the proximity of eruptive rocks strongly suggests a genetic relation between the two. The veins and rhyolites should probably be considered different expressions of the same general phenomenon.

LATE CRETACEOUS OR EARLY EOCENE DEPOSITS.

The deposits formed during the earlier period of mineralization present a great variety of types. Some are inclosed in gneiss, some in granite, some in Algonkian sedimentary rocks, and some in Paleozoic limestones, dolomites, quartzites, and shales. In internal make-up the deposits comprise pyrite gold veins, chalcopyrite gold veins, lead-silver deposits, cobalt-nickel deposits, and tungsten deposits. In form they vary from fissure veins to lenses in schist and replacements in limestone. Notwithstanding these differences in the nature of inclosing rock, in mineralogy and in form they have many points in common. All gradations exist between pyrite and chalcopyrite gold veins, although generally either chalcopyrite or pyrite greatly predominates. In all types galena is present, though only locally in commercial amounts, and gold is equally widespread. The tungsten deposits seem to be a special phase of the chalcopyrite gold veins and the cobalt-nickel deposits also are closely related to veins of this type. Throughout the deposits here grouped, coarsely crystallized quartz is characteristic.

From these gradations and similarities, and as all the deposits antedate the Eocene erosion surface and are later than the Carboniferous, it is thought that they represent one period of mineralization. They are all characterized by mineralogic associations, which mean deposition at great depth, at least 4,000 or 5,000 feet, yet they are cut

by the Eocene surface, and hence can not be younger, say, than the early part of that erosion cycle. On the other hand, many of the veins are inclosed in, and hence are younger than, late Cretaceous granite. This greatly diversified group of deposits, therefore, is considered as of late Cretaceous or early Eocene age.

The gold veins (see p. 62) are believed to be definitely related to the granite, and as the other types of deposits appear to be merely variations from them, it would seem to follow that all the deposits are related to this great igneous mass. It is noteworthy that the lead-silver and cobalt-nickel deposits differ more widely from the gold-quartz veins than do any of the others. With the former quartz diorite is closely associated and with the latter diabase. These rocks, both of which occur as dikes, are probably differentiations from the granite. On the other hand, acidic porphyries and orthoclase-bearing lamprophyres commonly accompany the gold veins.

ABSENCE OF CONTACT-METAMORPHIC DEPOSITS.

The absence of important contact-metamorphic deposits in Lemhi County is noteworthy. Indeed, the Bruce estate, Spring Mountain district, is the only place where contact metamorphism enters into the genesis of the ore bodies. The explanation of the lack of this phenomenon probably involves two factors—the absence of the more acidic intrusions in contact with limestone and a lack of tendency on the part of the intrusions to cause contact metamorphism. Of these the former is thought to be the most important, as limestones are far more susceptible to such alteration than are schists and quartzites. It would be expected, however, that the broad areas of schist intruded by the granite in the western part of the county would show noteworthy contact metamorphism. But here a difficulty arises, for the schists have suffered extensive regional metamorphism, and although it is thought that contact metamorphism is superimposed upon it locally the extent of this action is not known. Certain it is that metallization in connection with such metamorphism as is known (except in the Bruce estate) is negligible; hence it is believed that the magma lacked those properties which elsewhere in the State have given rise to ore deposits along its contact.¹

FUTURE OF MINING IN LEMHI COUNTY.

The outlook for a steady growth in the mining industry of Lemhi County is bright. It is thought that most of the free-milling gold ores have been exhausted, but in a heavily wooded and rugged mineral-bearing country there is always the probability of new discoveries.

¹ Lindgren, Waldemar, The genesis of ore deposits: Trans. Am. Inst. Min. Eng., vol. 30, 1901, pp. 721-722.

A large tonnage of base gold ore remains and this will be worked eventually, even though much of it is too low grade to ship other than as concentrates. Placers are expected to become more productive in the future than they have been during the last few years, through the introduction of dredges, which have converted ground heretofore considered valueless for mineral into an asset.

The copper deposits of the area are not developed sufficiently to justify a forecast, but increased production may be expected.

The lead-silver reserves have been largely extended during the past two years. At present most of the ore is coming from three mines, but it is probable that others will enter the list from time to time. This type of deposit has little or no surface expression, and minerals of the gossan are earthy in appearance; hence new and important discoveries may be expected.

The known cobalt-nickel deposits of the county are of uncertain value under existing market and mining conditions. Of the tin deposits little is known. The outlook for a moderate production of tungsten is encouraging.

Lignite has been worked from time to time near Salmon and Baker, but it is highly improbable that it will become of even local importance. As fuel it can not compete with coal shipped in from Wyoming, and if used for producer gas it would be unable to compete with the abundant water power available.

MINING DISTRICTS OF LEMHI COUNTY.

SCHEME OF TREATMENT.

In the following pages each of the 19 mining districts in Lemhi County is dealt with separately. The order of treatment is geographic, beginning at Nicholia in the southeast corner of the county and going north along portions of the Lemhi Range and the Beaver Head Mountains as far as Gibbonsville, thence west to Mineral Hill, and thence south to Parker Mountain, in the southwestern part of the county. This arrangement groups the lead-silver deposits among the districts first treated; the earlier gold veins follow, and the two districts containing late Tertiary gold veins come last.

NICHOLIA DISTRICT.

HISTORY AND PRODUCTION.

The Nicholia mining district, well known to the older miners of Idaho through its principal property, the Viola mine, is situated in the southeast part of Lemhi County, and includes a small area along the west face of the Beaverhead Mountains. The Viola claim, situated at an elevation of 8,700 feet, 2 miles east-northeast from Nicholia

post office, was located in 1880 and is the oldest property in the southeast part of the county. Mining was begun in 1882, the ore being hauled to Camas, and thence shipped to Kansas City and Omaha for treatment. It is said that 5,000 to 7,000 tons of ore, averaging 50 to 60 per cent of lead and 10 to 12 ounces of silver to the ton, were thus transported. In the fall and early winter of 1885 two lead stacks were blown in and thereafter the ore was treated locally. Smelting operations continued without protracted intermissions until early in 1888, when depletion of the larger ore bodies began. About 1890 the entire enterprise was abandoned. The amount of lead bullion recovered by the Nicholia smelter for the two years of greatest activity is given in "Mineral resources of the United States" for 1886 and 1887 as 11,900 tons, worth about \$1,000,000. The amount of silver accompanying this bullion is not recorded, but an estimate of 300,000 ounces is probably not greatly in error. With silver at 92 cents, this raises the total production for the two years of greatest activity to about \$1,400,000. Figures given in the Engineering and Mining Journal (November 27, 1886) are the basis for an estimate of \$500,000 total production prior to the construction of the smelter. Allowing an equal amount for the waning period of activity, it seems that an estimate of \$2,500,000 for the total production of the Nicholia district is not far from correct.

Prospecting has been pursued continuously in the vicinity of the Viola mine, but so far no important discoveries have been made. In 1905 the old workings were opened and an extensive search made for the continuation of the ore bodies but without success.

GEOLOGY AND ORE DEPOSITS.

The country rock is blue and gray limestone, overlying massive fine-grained quartzite. The main tunnel crosses a north-south anticline recorded by dips of 40° W., gradually changing to flat lying, and then to dips of 60° E. No igneous rocks were seen during the hasty visit to the property, but granite is said to lie about 4 miles north.

The ore occurred as three large bodies connected by stringers. Although irregular in thickness they were remarkably continuous for several hundred feet along the strike of the vein. Along its dip the vein was nearly horizontal for 400 feet, then within a short distance it assumed a dip of 45° and held it for 70 feet; it then became nearly horizontal again, and terminated in a zone of broken ground.

The ore was lead carbonate with much iron and manganese oxide intermixed and ran from 35 to 60 per cent of lead and 4 to 14 ounces of silver per ton.

SPRING MOUNTAIN MINING DISTRICT.**SITUATION AND ACCESS.**

The Spring Mountain mining district is situated in the southeastern part of Lemhi County, on the east slope of the Lemhi Range near its summit. Hahn, a settlement of perhaps 100 individuals, is the distributing center for the district. It is reached by wagon road from Gilmore, 8 miles to the north. Prior to the completion of the Gilmore & Pittsburgh Railroad, which was extended to Gilmore in 1910, the most accessible railroad point was Dubois, 75 miles to the southeast.

HISTORY AND PRODUCTION.

Many of the claims in the district were located in the early eighties, when profitable operation at the old Viola mine across the valley inspired prospectors to reach out into the surrounding country. For a few years a little ore was sent to the Nicholia smelter. In the spring of 1909 a smelter of 50 tons capacity was built at Hahn, and made a 17-day run that summer. It was refired in August, 1910, and ran for 21 days. The failure of the enterprise seems to have been due to a lack of funds sufficient to carry on exploration on bonded properties, or to buy ore from other sources. Although these futile efforts have given the district a setback, yet mineralization is widely distributed in the area, affording abundant justification for intelligent and legitimate prospecting.

The production of the district is not known, but an estimate of \$50,000 can hardly be much in error.

PHYSIOGRAPHY.

The Spring Mountain district includes the summit and eastern slope of Lemhi Range from Long Canyon south for about 6 miles. Several deep, narrow gulches extend toward the summit, terminating in deep cirques whose western rims form the crest line of the range. Conspicuous among these are Dry Gulch in the northern part of the district, and Spring Mountain Canyon in the southern part, most of the mines being located about the head of the latter.

Surface waters are notably lacking in the area, the streams forming Lemhi River heading about 10 miles to the north, and Birch Creek resulting from springs about an equal distance to the southeast. Within the area melting snow furnishes considerable water, which quickly sinks beneath the surface. In places it reappears as springs on the upper sides of the unfractured quartz diorite dikes, flows across them as small streams, and disappears in the greatly jointed limestone on the lower side. It is these springs far up the mountain face which gave the district its name.

Summit areas within the district present a general accordance in elevation, and many of them are comparatively flat-topped. This is the more remarkable, as the rocks composing the range are steeply folded and present unequal resistance to erosion. These areas are imperfect remnants of the broad plateau which resulted from the elevation of the Eocene peneplain described elsewhere in this report.

GEOLOGY.

The country rock of the Spring Mountain district comprises a great series of late Paleozoic sediments which strike N. 10°–20° E. and in general dip 40° SE. They present a considerable thickness, at least 1,200 feet being exposed in uninterrupted order in the steep eastern face of the south cirque at the head of Spring Mountain Gulch. This exposure, as seen from the opposite rim, appears to be limestone throughout and is composed of beds from 8 inches to 6 feet thick, principally white and gray, but with many bluish layers variously distributed. A small portion of the section along the road from Hahn to the summit, at an elevation of 7,000 feet, follows. Here the beds strike N. 20° E. and dip 85° NW.

Part of section of Devonian beds, Spring Mountain district.

	Feet.
Fine-grained blue siliceous limestone.....	10
Fine-grained white crystalline limestone.....	20
Alternating blue and white bands grading into blue limestone....	16
Light-gray fine-grained limestone with a few cherty partings.....	45
Bluish-gray limestone.....	25
White limestone (base).....	20

Fossils were not found in the south part of the district, but the search for them was not exhaustive. On the lower slopes of the range, near the north boundary, a suite of material was gathered, regarding which Mr. Girty says in part: “I believe, therefore, that lot 3 is of upper Mississippian age, but owing to the difficulty of the material there is in this a chance for error.” The ore deposits at Spring Mountain, however, lie west of these beds and on lithologic grounds are thought to be principally in the Devonian part of the section, as outlined in the chapter on general geology.

Three or four quartz diorite dikes, one having a width of 1,500 or 2,000 feet but the others of 50 feet or less, follow the general strike of the formations. These dikes usually present no special topographic expression, but can be followed from a distance by their grayish-brown soil, which stands out in contrast to the light-gray mantle resulting from the inclosing limestone. Contact metamorphism was noted only along the large dike, the minerals developed being calcite, coarse flecks of muscovite, biotite, magnetite, vesuvianite, abundant forsterite, and a little garnet, the last two being of microscopic size.

The dikes are obviously younger than the sediments which they cut and older than the present topography, the higher reaches of which they traverse. They are of late Cretaceous or early Eocene age (p. 46).

ORE DEPOSITS.

Prospecting sufficiently fruitful to offer reasonable encouragement to further effort has been carried on along a belt about half a mile wide which starts near the summit west of Hahn and continues northward to the end of the district, gradually dropping down the eastern slope to a point about halfway between the summit and the valley at the northern boundary. All the deposits are contained in limestone, although numerous quartz diorite dikes follow the ore zone.

The ores mined are principally lead-silver, though a low-grade copper deposit is being prospected on the Bruce estate. All the deposits, save perhaps those of copper, are replacements, in type very similar to those at Gilmore (p. 94). The copper deposits were not seen, but from the great amount of magnetite in specimens of the ore, and their stated occurrence along the contact of a large "syenite" (probably quartz diorite) dike, they are thought to have resulted from contact metamorphism.

Ground-water level is always important, both because of increased difficulties in mining and because of the changes in the tenor and mineralogy of the ore which usually accompany it. At present most of the development in the Spring Mountain district is above ground-water level, but its distance above varies greatly from place to place because of unfractured dikes which cut the intricately jointed limestone series and serve as submerged dams, causing the ground water to rise to their upper edge before escaping. In general, on the upper side of any dike the water table will be found at about the elevation of the dike in the bottom of the adjacent canyon. On the lower side the elevation will be determined by the next dike down the mountain side, and so on to the most eastern dike, beyond which the springs at the head of Birch Creek will probably be the controlling factor, allowing, however, a reasonable gradient for the water table.

The ore so far mined in the district has been principally oxidized material, although the Lemhi Union and possibly one or two other properties have furnished some sulphides. The general tenor and make-up of the ore from the district can be readily seen from the table of smelter analyses given on page 65.

As the veins are inclosed in highly folded Devonian (?) and Carboniferous strata and are truncated by an Eocene erosion surface, it follows that they are post-Devonian (?) and pre-Eocene in age. The age can not be determined from local evidence, although general

considerations (p. 68) lead to the conclusion that they are late Cretaceous or early Eocene.

The deposits are clearly tabular in outline and correspond to the major fractures in the limestone. In places the ore expands along bedding planes or cross fractures and in other places bunches are isolated in the wall rock. The broader features thus indicate replacement activity, the solutions being guided in their movements by strong north-south fractures, perhaps fissures. No relation was noted between the lead-silver veins, and the quartz diorite dikes save their general parallelism. The mineralogy and reported relations of the copper deposit on the Bruce estate suggest that it is a contact phenomenon caused by the quartz diorite.

MINES AND PROSPECTS.

In the following descriptions only the properties visited will be mentioned. The list is by no means complete, but it serves to give concreteness to the general discussion.

LEMHI UNION MINE.

The Lemhi Union mine, situated at an elevation of 9,000 feet near the head of Dry Gulch, in the northern part of the district, is one of the principal properties. The vein, which is inclosed in blue limestone, strikes N. 20° E. and dips 80° NW. As is common in this general area the limestone corresponds in strike with the vein and dips 40°–50° SE. Quartz diorite dikes cross the gulch both above and below the mine. The deposits were not seen below the surface, for at the time of the investigation the shaft was almost closed by ice resulting from surface waters trickling down the walls and freezing. Analyses of two lots of ore handled by the Hahn smelter show lead-silver ore almost identical with the Gilmore ore deposits (p. 65). One of these lots, amounting to 57 tons, ran 39 per cent lead, 12 ounces silver, 16 per cent iron, 10 per cent silica, and 4.3 per cent calcium oxide.

COLORADO GROUP.

About half a mile east of the Lemhi Union mine is the Colorado group, where some ore has been found. The property is of special interest, however, because it shows better than any other visited the influence of the quartz diorite on the adjacent limestone. A tunnel crosses the margin of the dike at a small angle, giving an excellent exposure for about 35 feet along the contact. The metamorphism consists in the development of calcite, coarse flecks of muscovite, and some biotite, all readily recognized megascopically. In addition, pepper-like specks are scattered through much of the rock. When microscopically examined these prove to be forsterite, one of

the olivines, and some garnet crystals. The quartz diorite dike causing the metamorphism is said to be from 1,000 to 2,000 feet wide.

Ore minerals have not been found in the tunnel just referred to, but on the hill above a vein striking north and south and dipping 45° W. furnishes argentiferous galena, manganese oxide, pyrite, and chalcopyrite as primary constituents in a siliceous gangue. Oxidation is fairly extensive.

No genetic relation was observed between the contact silicates first mentioned and the metallic minerals just enumerated.

BRUCE ESTATE.

A group of claims known as the Bruce estate extends along the mountain slope near its summit for 2 miles south from Dry Gulch. The property was not visited. Lead-silver ore is reported from several claims, but the most interesting feature is a big low-grade copper deposit found in association with large quantities of magnetite. The deposit occurs on the side of a big dike which is called "syenite" by the miners, but which is probably quartz diorite, as an abundance of the latter and none of the former was noted in the boulders of the gulches below.

ELIZABETH AND TEDDY MINES.

These properties, which are about 1,000 feet apart, are situated on the slope of Lemhi Mountain toward Little Lost River at an elevation of 9,700 feet above sea level. Each mine has a few hundred feet of development. The ore is hauled half a mile to the rim of a cirque, 2½ miles west of Hahn, where it is trammed to the bottom, and thence hauled to the smelter. The veins have a general north-south strike and are inclosed in flat-lying limestone and subordinately in quartzite. Together, the properties furnished the Hahn smelter with 400 tons of ore averaging about 20 per cent lead, 11 ounces silver, 10 per cent iron, 21 per cent silica, and 10 per cent calcium oxide.

OTHER PROPERTIES.

The Red Warrior, Iron Mask, Galena, and Excelsior are important among the properties which were not visited. All are held for lead-silver.

TEXAS DISTRICT.

SITUATION.

The Texas mining district comprises an irregular area of about one township in the southeast part of the county near the head of Lemhi Valley. It lies immediately north of the Spring Mountain district, Long Canyon being generally taken as the dividing line. To the north and west not even approximate boundaries are recognized. The junction district lies about 18 miles to the north, and the Blue

Wing district well beyond the summit of the mountains to the west. On the east the wide valley of Lemhi River, deeply filled with Miocene lake beds, forms at present a natural boundary.

Gilmore (Pl. XIV.), a mining camp of possibly 500 inhabitants, is the local post office and supply point for the district. It is reached by the Gilmore & Pittsburgh Railroad, which connects via Junction and Bannock Pass with the Oregon Short Line at Armstead, Mont.

The district is primarily important for its lead-silver ores, although one gold vein (Allie) and one silver vein (Silver Moon) are recognized.

HISTORY AND PRODUCTION.

Inspired by the great bodies of lead-silver ore at the Viola mine, situated across the Lemhi Valley, prospectors located many claims in the surrounding country in the early eighties. The most promising among these claims occupied a belt about 12 miles in extent along the east face of the Lemhi Range, a little north of west from the Viola deposits. The Texas district comprises the northern portion of the mineral belt thus early discovered and largely staked out. In it prospecting continued, and mining was carried on in a desultory way for a number of years, some ore being hauled to the Nicholia (Viola) smelter; but with the abandonment of that property about 1890, whatever enthusiasm may have prompted work in the Texas district died out and for 10 or 12 years there was little progress.

In 1902 a group of claims, the chief of which now constitute the Pittsburgh-Idaho property, were purchased by F. G. Laver, of Dubois, Pa., for himself and associates. Early development revealed, at a depth of about 200 feet, ore bodies which greatly exceeded the anticipation of the owners. In a short time considerable ore was blocked out and the method of treatment became a problem of prime importance. The old Nicholia smelter, which had afforded ready market in the early days of the district, had long since been dismantled, and shipping to the large reduction works in Utah or Montana necessitated a haul of 85 miles by wagon in addition to the railway charges. The alternatives were to erect a local plant or await railway transportation. The wagon haul to Dubois, Idaho, was adopted and continued, during the open season, for four years. The roads were so destructive of wagons, however, that it became almost impossible to keep them in repair, and in the fall of 1906 a traction engine with a train of four steel wagons, each of 15 tons capacity, was put on the road. The cars were not equal to the continued strain even though the route was almost ideal for such transportation, and after a dozen trips this method of haulage was abandoned.

From the fall of 1907 until the spring of 1910 the Pittsburgh-Idaho mine was idle, awaiting the completion of the railroad which was being built from Armstead, a station on the Montana branch of the



MINING CAMP OF GILMORE, FROM NORTHEAST.



Oregon Short Line, 90 miles south of Butte. During this period the Latest Out mine became active, the ore being hauled to Dubois. In the spring of 1909 several of the smaller properties supplied small amounts of ore to a new smelter which was opened at Hahn, in the Spring Mountain district.

With the extension of the railroad to a point within 9 miles of Gilmore by June, 1910, the camp took on new life and has been increasingly active ever since. In 1910 the railroad was within 1½ miles of the producing mines of the district.

The total production of the Texas district probably falls between \$2,000,000 and \$2,500,000. Somewhat more than 700 tons of lead bullion and over 100,000 ounces of silver are said to have been derived from ores treated by the old Nicholia smelter between 1885 and 1888. From 1902 until 1908 about 6,270 tons of lead bullion and 325,000 ounces of silver were extracted from ores hauled 85 miles to Dubois, and thence shipped to the smelters in Utah. Between June and October, 1910, about 1,600 tons of lead and 72,000 ounces of silver were produced from Texas district ores, and for the fiscal year from September 1, 1910, to August 3, 1911, 7,750 tons of lead and 351,500 ounces of silver were produced.¹

Prior to 1910 the district produced almost no gold, but during the spring of that year a promising gold-bearing lode was discovered on the Martha claim of the Allie group.

PHYSIOGRAPHY.

Elevations in the district range from about 7,000 feet in the eastern part to more than 10,500 feet in the mountain areas along the western border. The local topographic features are due to numerous deep canyons, which extend back well toward the crest line of an otherwise even mountain slope, which rises abruptly to a height of almost 4,000 feet above the western margin of the broad valley of Lemhi River.

These mountain valleys are invariably U-shaped and near their junction with the lowland present the irregular topography characteristic of terminal moraines; their headward terminations have striking amphitheater-like forms, in the basins of which little lakes are not uncommon.

There are no important streams in the district. Those which rise in the mountains flow for short distances only, the waters sinking before the mouths of the canyons are reached. In the lowland northeast of Gilmore numerous springs occur at elevations of about 6,800 feet; these

¹ The figures for the period prior to Sept. 1, 1910, are largely derived from the known tonnage, estimating lead at 35 per cent and silver at 16 ounces per ton of ore. The silver is not far from correct, although it is quite possible that the early shipments averaged higher than 35 per cent lead. The 8,000 tons of 60 per cent concentrates from the Pittsburgh-Idaho mill and the early production of rich silver ore from the Silver Moon property were considered individually.

give rise to Texas Creek, an important member of the group of streams which by their union constitute Lemhi River. The water supply for Gilmore is derived from a lake at the head of Meadow Lake Gulch, whence it is conveyed to the mines and settlement some 3 miles distant. Although abundant water is thus supplied for domestic purposes, a sufficient supply for concentration on a large scale can be secured only by heavy outlay. Considerable water power can be developed within 20 miles to the north.

GEOLOGY.

SEDIMENTARY ROCKS.

A great succession of sedimentary rocks, striking north and south and for the most part dipping about 45° E., occupies most of the district. Cambrian, Ordovician, Silurian (?), Devonian (?), and Mississippian formations are present. The basal series is made up of clear-white, fine-grained quartzite and is at least 2,000 feet thick. It is well exposed above Meadow Lake. Conformably above it is a series of massive blue dolomitic limestones about 500 feet thick, which is assigned to the Ordovician. Then follows 300 feet of massive white dolomitic limestone of Silurian (?) age. The strata next above comprise about 2,000 feet of thin-bedded blue and white dolomitic limestones, with here and there a siliceous band. This series is tentatively considered Devonian. Its upper contact was not seen, although it is presumably conformable with the Mississippian. The latter formation is exposed along the lower slopes of the range south of Long Canyon.

Above the Paleozoic rocks along the east side of the district, and separated from them by a marked angular unconformity, is a series of Miocene lake beds, the thickness of which is not known, although more than 200 feet appears in some exposures. If the general history of these beds, as given on pages 35-40, is correct, it is altogether probable that along the eastern edge of the Texas district they are more than 2,000 feet thick. As seen in the railroad cuts they present chalk-white slopes cut by regularly bedded layers of light bluish-gray fine volcanic ash, in places almost pumiceous enough to float on water. The bedding is shown by slight variations in color, the individual bands ranging from half an inch to 4 inches in thickness. In some places thin layers of limestone, slate, and quartzite pebbles are interbedded with the tuff, and in others pebbles and sand are intermixed with it.

The lake beds are traversed by minor faults, usually trending east and west. Dips above 25° were not noted, this maximum being recorded just north of the low divide which extends across the valley. South of the same divide the beds dip 15° S., thus presenting an east-west anticline, the axis of which lies about in line with the south

branch of Long Canyon. Indeed, as seen from the valley, the limestones traversed by Long Canyon present a similar anticlinal structure. Here, however, the anticline crosses at right angles a series with an otherwise steep eastward dip, the resulting attitude being a dip to the northeast on the north side of the canyon and to the southeast on the south side.

Not much is known of faulting within the area because the different formations were but imperfectly recognized outside the type locality. West of Gilmore the structural relations are simple, but east of it the rock exposures suggest duplication of formations. Over most of the district, however, the beds dip from 40° to 50° E., thus suggesting the absence of much faulting. On the other hand, displacements were recognized in some of the underground studies. On the Martha claim a fault extending N. 10° E. presents a downthrow of possibly 225 feet on the west. A displacement, possibly the northward extension of the one just mentioned, was noted in the Little Gilmore Tunnel. It strikes N. 10° E. and records a downthrow of 55 feet on the west. In both places the fault plane dips approximately 45° W.

Crossing the north-south structure is a series of east-west vertical fissures, which, beneath the surface, commonly stand as open channels from 1 inch to 5 feet wide. In many places they are lined by beautiful aragonite crystals, and in others are loosely filled with débris from the sides. There seems to have been little displacement along them, and this, together with their obviously recent formation, suggests that they are incident to the low east-west anticline clearly recorded in the lake beds to the east. Parallel to these are older fissures, some of which are mineralized near their intersection with the north-south veins. Jointing is conspicuous throughout both the quartzite and limestone portions of the series.

IGNEOUS ROCKS.

Igneous rocks are not abundant in the Texas district, a few quartz diorite porphyry dikes being the only representatives. These are poorly exposed, so that rare outcrops and prospect openings are the only means of determining their distribution and extent. At least two dikes striking N. 10° to 15° E. are present, the east one extending through the Glen and Neversweat claims, above Gilmore. Running west of north are similar dikes, possibly spurs from the others.

In general appearance the dike material is a dark-gray dense porphyritic rock with many medium-sized dull feldspar phenocrysts. On microscopic examination both quartz and biotite are seen to be present in important amounts. The groundmass is microcrystalline and all parts have a higher index than Canada balsam. In many of the feldspars and in much of the groundmass calcite and sericite are conspicuous. The rock may best be designated quartz diorite porphyry.

The dikes were intruded in part at least after mineralization, as shown by an exposure in the upper workings of the Latest Out mine, where one of them cuts across the ore. That they are older than the present topographic features, on the other hand, is clear from an exposure at the head of Meadow Lake, where one of them is exposed in the cirque rim at an elevation of 10,500 feet. As the larger topographic features are post-Eocene, and the ore deposits are late Cretaceous or early Eocene, the dikes were intruded at about the beginning of the Tertiary.

ORE DEPOSITS.

DISTRIBUTION.

The known deposits of the Texas district occur in a comparatively narrow north-south belt bounded on the east by the Miocene lake beds of the Lemhi Valley and on the west by the quartzite that forms the crest of the range and thence dips eastward, disappearing beneath the limestones which inclose the veins.

The mineral locations are mainly along the walls of valleys which cut back into the otherwise regular mountain face, thus exposing the lodes. The mines at Gilmore are situated in such a valley. The Pittsburgh-Idaho mine appears in the south side of this depression near its head, and the Latest Out vein crosses its steep upper end. Several claims, not now operated but showing strong mineralization in places, are situated in Silver Moon and Liberty gulches south of Gilmore, and in Texas and Ulich gulches to the north. (See Pl. XV.)

RELATION TO STRUCTURE.

In general the lodes strike a few degrees east of north and dip west at angles varying widely but usually of more than 45°. Thus the course of the veins is parallel to the strike of the formations although their dip is generally opposite and steeper. This relation suggests that the fissures which the ores follow were formed when the rocks were folded into their present attitude, for it is apparent that fissures with dip toward the core of an uplift would result from the upbending of a great series of rocks with resistant quartzite at the base and inelastic limestone above.

Intersecting the veins at right angles are fissures, some of which are open and unmineralized; others, though seldom mineralized far from the north-south fissures which seem to have carried the solutions, bear a definite relation to the ore shoots. An apparent exception was noted on the Dorothy claim, where an east-west fissure, well removed from any known north-south ore-bearing vein, is locally mineralized. As some of the east-west fissures are barren and others carry ore, it is thought that the east-west breaks occurred

at two distinct periods. In a few places where the open or younger channels cross soft north-south mineral veins, loose ore has worked out along the former for several feet; this, however, is the result of purely mechanical processes. An illustration of such condition is seen at the intersection of the Allie crosscut with the Martha vein.

Although the deposits are but rarely offset by faults (all small), slickensides and crushing within the ore are common, implying that movement since the ore deposition has largely followed the original lines of weakness. The faults which cut the veins follow the beds in such a way as to indicate a settling toward the Lemhi Valley of successively overlying strata. The largest offset of this kind is in the west vein on the 400-foot level of the Pittsburgh-Idaho mine, where a displacement of 10 feet is recorded.

The ore deposits, although in some places extending out along bedding planes and in others abruptly evading some rock not as susceptible to dissolution as its neighbor, are on the whole to be considered as tabular bodies and classed as veins. Figure 10 (p. 101) illustrates the veinlike character shown in the Pittsburgh-Idaho mine, and figure 15 (p. 106) illustrates replacement conditions in the Latest Out deposit. In the Jumbo mine the ore is clearly of replacement origin, narrow vertical stringers serving apparently as feeders to larger masses which extend out along the bedding (fig. 16, p. 109). The Latest Out ore body is decidedly tabular in outline, but isolated bunches of ore within the walls adjacent to the vein are common. Figure 14 (p. 105) illustrates a condition which is probably a combination of replacement and fissure filling.

ORES.

The deposits are predominantly lead-silver, only two exceptions being known. One of these is the ore shoot in the Martha vein, which carries no lead, but averages about \$12 a ton in gold; the other is the Silver Moon vein, which has produced silver almost exclusively. Copper rarely exceeds a fraction of 1 per cent. Zinc is present in nearly all the deposits, but has not been found to exceed 9 per cent in broad averages.

The structure of the ore is greatly obscured by the extensive oxidation which prevails throughout the present workings. As exposed the ore is a mass of earthy carbonate heavily stained with iron and manganese and usually showing a faint metallic luster. Two types of lead-silver ore may at present be distinguished—oxidized ore consisting of lead carbonate, iron oxide, and other minerals, and primary ore made up of galena, pyrite, and zinc blende.

All the development is well within the zone of oxidation, so that such primary ore as is found occurs in spots which have escaped the influence of surface waters. In the Latest Out mine pockets of

sulphide are found as bunches isolated in the limestone adjacent to the veins, and occasionally as cores within large blocks of secondary ore. In the Pittsburgh-Idaho mine, near the bottom of the east vein, where downward-percolating waters are checked by a cross seam of clay, some stopes afford galena and pyrite. In the Jumbo mine oxidation is less advanced than elsewhere, probably on account of little fissuring in connection with the deposit. The primary ore thus exposed is made up of galena, quartz, pyrite, and zinc blende, decreasingly important in the order named.

Probably more than 85 per cent of the total ore exposed in the lead-silver deposits is composed of minerals resulting from the oxidation and carbonation of the group just enumerated. Cerusite and iron oxide are by far the most conspicuous. Anglesite is frequently seen as a narrow band around a core of galena. (Pl. X, B, p. 64). Smithsonite is common as botryoidal linings of small cavities and as stringers along joints. Calamine occurs as needle-like crystals extending from the sides of vugs otherwise lined by smithsonite. Manganese oxide is omnipresent as stains within the ore and less frequently as dendrites on the inclosing limestone. Pyromorphite is rare, cerargyrite probably very common but in exceedingly small grains, malachite unusual, and minium very exceptional.

The general tenor and make-up of the ore are shown in the table on page 65.

In striking contrast to the composition of the lead-silver ores is that of the gold ore of the Martha vein, from which several shipments have been made. Like the lead-silver ores, the grade is remarkably uniform. The analysis below may be considered typical. In appearance the ore is a dull, earthy, more or less incoherent mass, heavily stained by iron and manganese.

Analysis of smelter ore from Martha gold vein.

Gold	ounce..	0.515
Silver.....	do....	.70
Silica.....	per cent..	11.7
Iron.....	do....	47.7
Lead.....		None.

This vein carries gold in commercial amounts but contains very little silver and no lead; in all the other veins, except the Silver Moon, the relation is the reverse. The Silver Moon is said to have produced silver almost exclusively.

GROUND-WATER LEVEL AND OXIDATION.

Nowhere in the mines of the district has ground-water level been reached. Some idea of its depth, however, may be formed from a consideration of the large springs which appear in great numbers in the adjoining valley at elevations of 6,600 to 6,700 feet. These

springs, which undoubtedly drain most of Texas district, appear about 3 miles northeast of the mines at Gilmore. Just what slope the water table has between the mines and the springs is not known, but with open east-west fissures, some of which are 2 feet or more wide throughout considerable parts of their length and with intricate north-south jointings, it seems very probable that the increase in elevation of the water table from the springs to the mines is comparatively slight, probably much less than 100 feet to the mile. A study of the general geology of the district discloses another factor which probably has a bearing on ground-water level. Comparatively recent dikes of quartz diorite porphyry cut north and south through the area. They did not participate in the folding which caused the steep eastward dip and are probably antedated by very much of the jointing in the limestone. They have, however, been involved in the movement which developed the east-west open fissures. It thus appears that with submerged dams broken in only a few places, as compared with the intricate jointing elsewhere prevailing, the water level will be somewhat higher west of the dikes than east of them. It thus appears that permanent water level will probably be found in the vicinity of the Pittsburgh-Idaho mine at 6,800 to 7,000 feet. In the territory farther west, as at the Latest Out mine, it will probably be found at a somewhat higher level.

Throughout that portion of the deposit now developed oxidation is essentially complete. The mineralogic character of the primary ore in the lead-silver deposits is not fully known, but chance bunches of unaltered ore indicate that the present deposits are derived from argentiferous galena, pyrite, and sphalerite, together with minor amounts of some manganese mineral and a little chalcopyrite. Analogy with other lead-silver deposits in the State, notably those at Cœur d'Alene and Wood River, suggests that siderite also may be present in the primary ore, but none was seen. The important chemical and mineralogic changes involved in the alteration of these ores have been the conversion of argentiferous galena to cerusite and cerargyrite, of pyrite to limonite, and of sphalerite to smithsonite. Anglesite occurs in several places as a narrow band between galena and cerusite. It is everywhere very subordinate in amount, clearly indicating that the transition to cerusite follows very quickly after the breaking down of the galena, even though the sulphate is probably always an intermediate form. Minium, calamine, argentite, and manganese oxide are other secondary minerals which occur, although only the last abundantly.

As the alterations noted in the deposits necessitate an increase of volume per unit of metal contained (pp. 66-68), and as the deposits are more porous now than formerly, a considerable extraction

of one or more elements must have taken place. From the relative rate of oxidation, and the relative solubility of the oxidation products, it appears that lead has remained essentially stable, iron has probably been somewhat removed, and zinc removed in considerable quantities.

From the above it is concluded that below the zone of oxidation lead will decrease slightly in amount per ton of ore. This follows from the conclusion that iron will increase somewhat and that zinc will probably increase materially. In other words, it is thought that there is a slight concentration of lead in the oxidized ore by reason of the leaching of other constituents of the deposit.

AGE AND GENESIS.

The deposits of the Texas mining district are of late Cretaceous or early Eocene age, although local evidence does not confine the limits so closely. The veins are obviously younger than the Carboniferous limestone, which is mineralized in places. They are younger than the quartz diorite dikes, for one of the latter cut the ore as shown in the upper workings of the Latest Out mine. The dikes in turn are older than the present topographic features, for they cut across the mountain tops, as near the head of Meadow Lake. As the present topographic features are post-Eocene, it follows from local evidence that the deposits are post-Carboniferous and pre-Oligocene. From broader considerations, however, it is thought that the deposits are late Cretaceous or early Eocene. (See p. 68.)

Alteration has been so complete that the ore itself retains few of those evidences of origin which are generally recorded in mineralogic structure and relations. That the deposits were formed at a depth of 2,000 feet or more is evident from their relations to the topography. The general features of the deposits indicate that both replacement and fissure filling have taken place. In the Pittsburgh-Idaho mine the east fissure continues downward after the ore has given out. In the Latest Out mine also the vein walls continue in many places after the ore has entirely ceased.

The veins are clearly older than the quartz diorite porphyry dikes which cut them. It is, however, interesting that throughout the Texas district and the Spring Mountain district to the south, these dikes are never far removed from the ore deposits, possibly indicating that the two have a common source. Broader considerations (p. 68) lead to the belief that the ores of the Texas district are genetically related to an underlying granitic or monzonitic mass corresponding to the great batholith extensively exposed in central Idaho to the west, probably in the Wood River district to the south, and at many places along the Beaverhead Mountains to the east.

MINES.

PITTSBURGH-IDAHO MINE.

Situation and development.—The Pittsburgh-Idaho mine is situated near the town of Gilmore, in the southeast part of Lemhi County, at an elevation of 7,800 feet above sea level. In 1910 the Gilmore & Pittsburgh Railroad had been completed to a point within $1\frac{1}{2}$ miles of the mine, thus affording ready transportation.

The history of this group of claims is essentially the history of the Texas district. (See p. 90.)

The production of the property prior to September 1, 1911, consisted of about 12,000 tons of lead bullion and about 500,000 ounces of silver, approximately 45 per cent of which was shipped during the fiscal year 1910–11.

Development has been largely confined to two of the five claims owned by the company, the Silver Dollar and the Sixteen to One. (See fig. 9.) On the upper levels the Silver Dollar was the more productive, but with increasing depth the ore shoots pitched south into the Sixteen to One ground, and at present that claim affords nearly the entire output.

The mine is worked from a double-compartment shaft sunk from an old tunnel level 100 feet above the present adit and about 110 feet below the surface of the ground. Although now entirely abandoned, the old tunnel is still the reference point in naming the several levels. Thus the present working adit is known as the 100-foot level. Below it the shaft continues for 300 feet, and from it drifts and crosscuts aggregating about 3,000 feet have been extended on the 200, 300, and 400 foot levels. From the latter an incline winze reaches to the 500-foot or deepest level.

Geologic conditions.—Throughout the workings blue fine-grained Devonian limestone, extensively jointed and locally greatly crushed, is the prevailing country rock. Within this are lenses (and possibly here and there a bed) of fine-grained white lime, the largest observed measuring perhaps 35 feet in maximum thickness. These lenses frequently protrude into the ore fissure in a most remarkable way, and almost invariably they are covered with slickenside surfaces recorded in a layer of talcky pulverized lime. In general the limestone dips from 30° to 50° .

Quartzite, which dips toward the mine, crops out about 4,000 feet to the west. It will not be encountered in the workings, however, until they have been extended 2,000 feet or more.

Ore deposits.—The ore bodies in the Pittsburgh-Idaho mine comprise two nearly vertical veins and a flat vein which connects them and continues in depth beyond the west one. (See figs. 10–12.) All strike N. 15° E., as does also the inclosing limestone, and each has a

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general westerly dip, opposite to that of the limestone. The east and west veins, however, are in some places vertical and in few dip less than 70° ; the flat vein mostly inclines at an angle of about 45° . The flat vein joins the east vein about 30 feet below the 200-foot level but

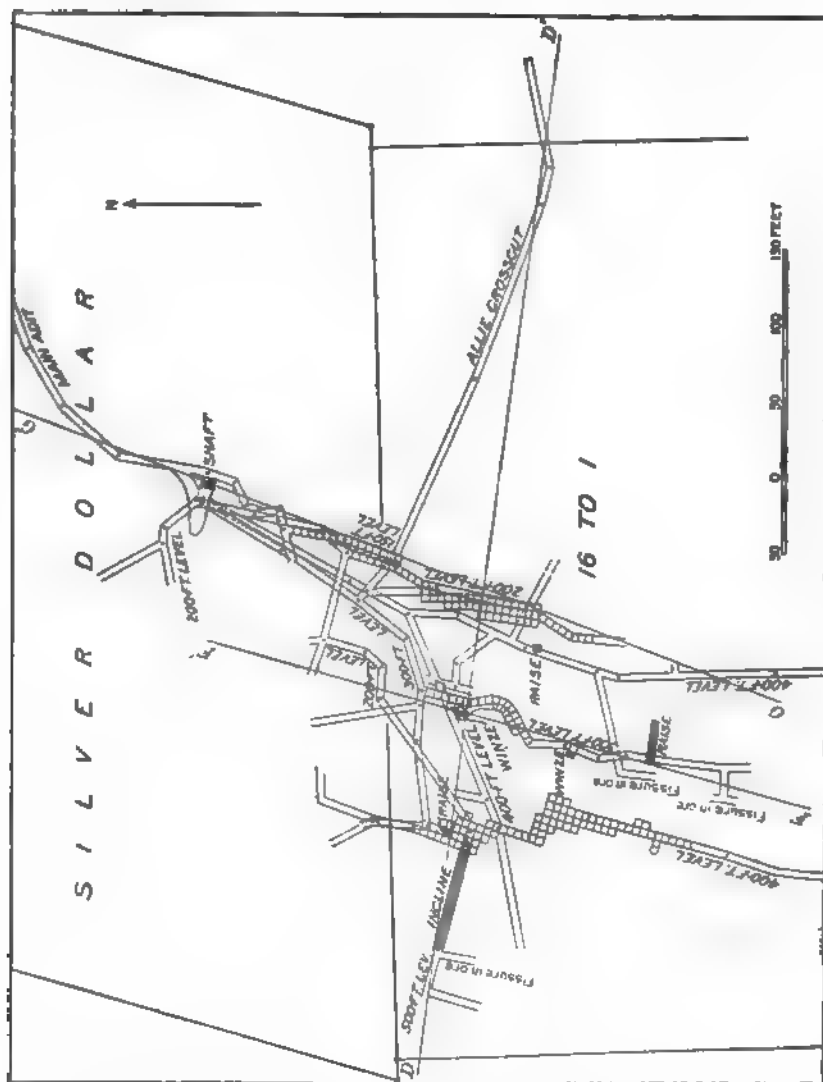


FIGURE 9.—Plan of part of underground workings of the Pittsburgh-Idaho mine, Texas district. Adapted from map by C. A. Peck.

has not been found to the east. Westward it continues across the west vein and is now being worked on the 500-foot level.

In general outline the deposits are tabular and clearly to be classed as veins, yet in detail they are irregular. Many small swells extend into the walls and in places spurs follow joint planes for short dis-

From these general relations it appears that the solutions depositing the ores entered along open fissures and that the principal deposition took place in cavities already existing. That the solutions were capable of replacing the limestone, however, is clearly shown by the isolated bunches of ore within the walls adjacent to the veins and also by the swells of ore into the wall rock without corresponding swells of wall rock into the ore on the opposite side.

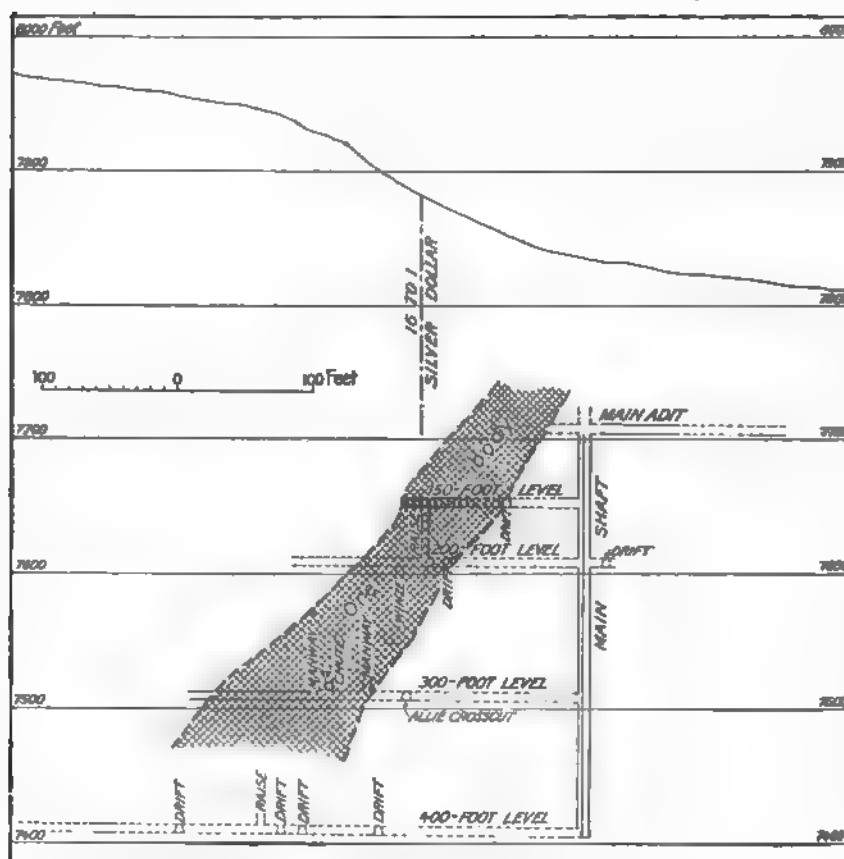


FIGURE 11.—Longitudinal section of east vein, Pittsburgh-Idaho mine, Texas district.

The ore material, all of which is at present derived from below the 200-foot level, is characterized by a high percentage of metallic elements, lead, zinc, and iron together constituting over one-half of the vein filling. The material occupying this part of the vein is very different from that which was originally deposited in it and which presumably still continues below the level of ground water. In this original material galena, pyrite, and sphalerite were abundant, but in the existing material the filling is earthy lead carbonate accompanied by abundant iron and manganese oxides. The zinc carbonate,

smithsonite, is common as druses in cavities of secondary origin and as a granular intermixture with the cerusite. Calamine was noted as radiating groups of needle-like crystals protruding from cavity walls otherwise covered by botryoidal smithsonite. (See Pl. X, C, p. 64.)

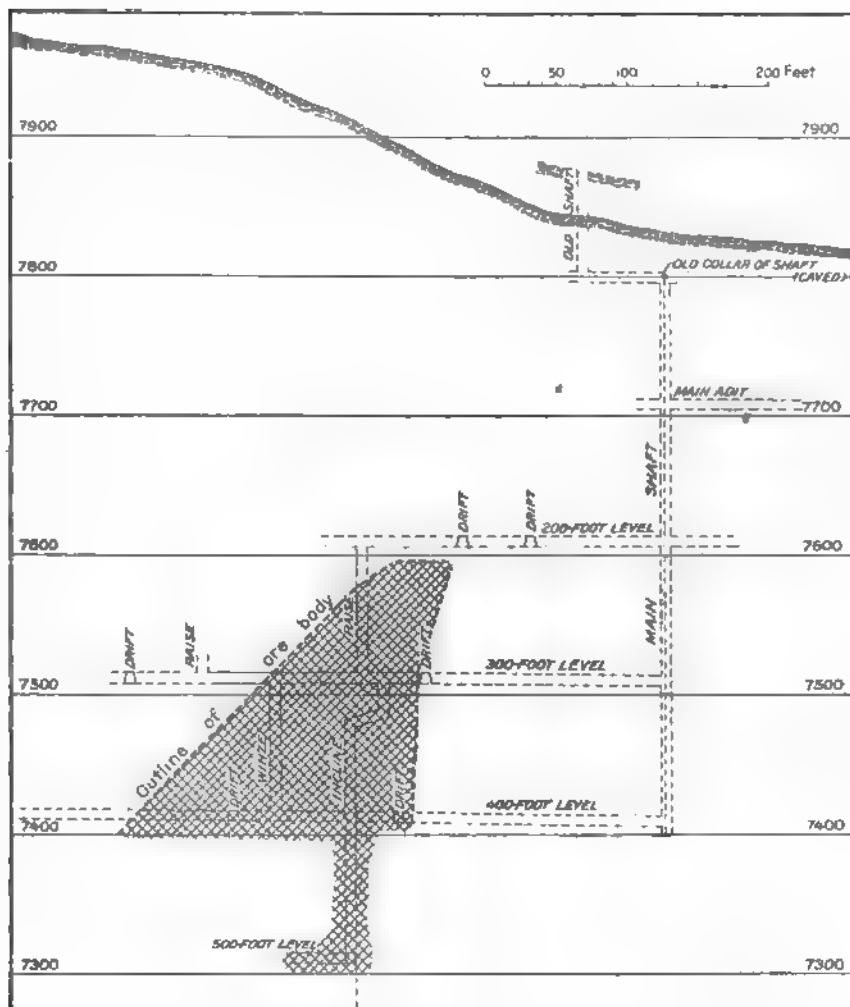


FIGURE 12.—Longitudinal section of flat vein, Pittsburgh-Idaho mine, Texas district.

The ore averages about 37 per cent of lead and 15.25 ounces of silver, and in the 500 feet of depth thus far attained little or no change has been noted in its tenor. As the ground-water level, and hence lower limit of oxidation, will probably be encountered at an elevation of about 6,900 feet above sea level, and the lowest level at present is 7,100 feet, it is probable that little change in the character of the ore will be encountered within the next 200 feet.

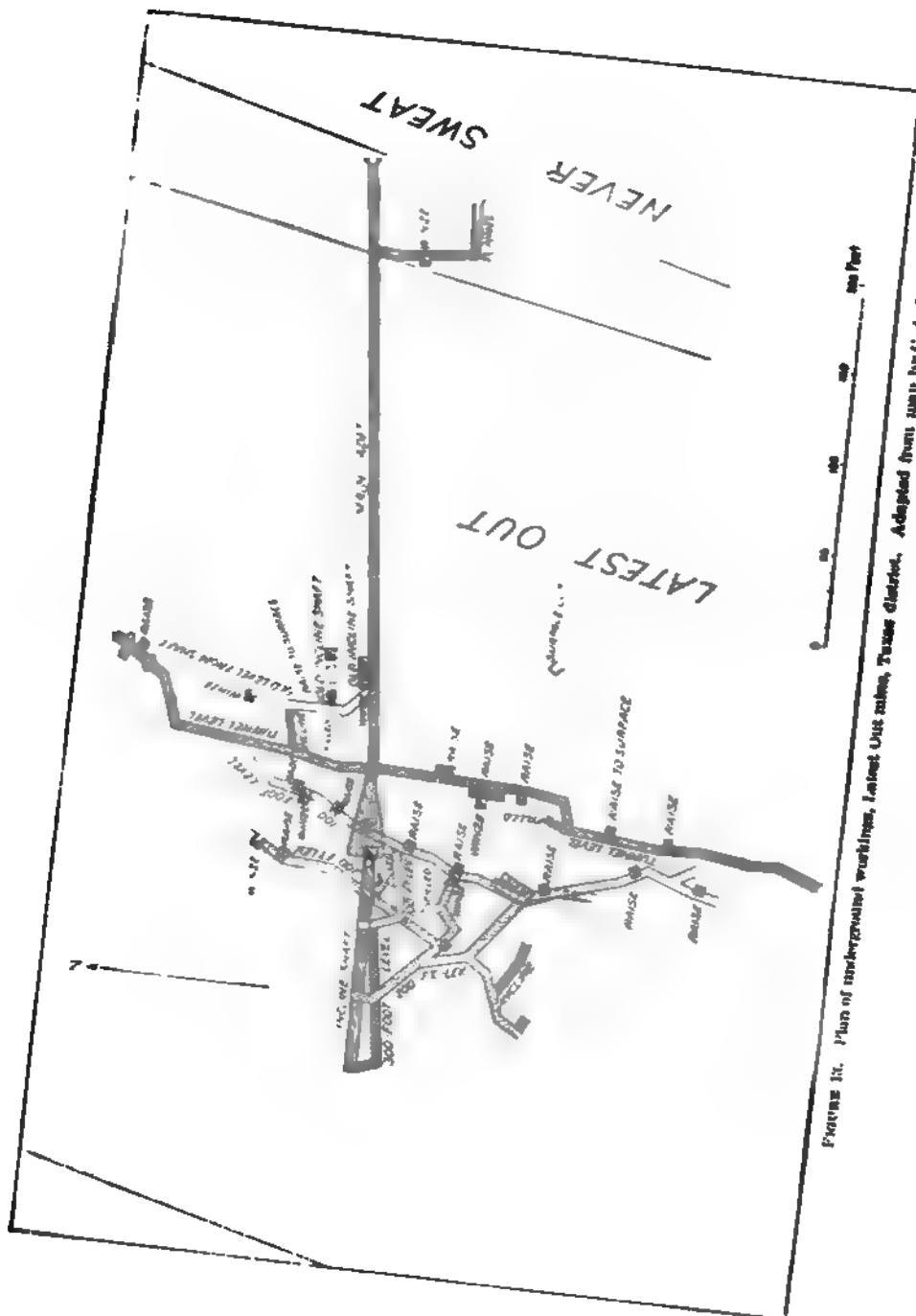


FIGURE 11. Plan of underground workings, Latest Out mine, Teton district. Adapted from 1901 U.S.G. & G. map.

LATEST OUT MINE.

Situation and development.—The Latest Out mine is situated in the central part of the Gilmore division of the Texas mining district. The property consists of one claim owned by the Latest Out Mining & Smelting Co.

Development consists of a tunnel which enters the hill at an elevation of 8,100 feet and intersects the vein 340 feet from the portal, whence an incline shaft extends 220 feet. Laterals aggregating 800 or 900 feet extend from the shaft at the 100, 200, and 300 foot levels. The ground above has been worked principally from openings farther up the mountain. These comprise 300 to 400 feet of development. (See fig. 13.)

The claim was located in 1880 and during the four or five succeeding years 1,200 to 1,500 tons of ore was hauled to the old Nicholiasmelter. Not until 1908, however, when Ralph Nichols gained control, was substantial development undertaken. In 1908 and 1909 about 200 tons of ore was hauled 85 miles to Dubois and thence shipped to Salt Lake. With the advent of the railroad in 1910, transportation costs were so reduced that mining and development were undertaken on the larger scale which has since continued. Up to September, 1911, the gross production was about \$350,000.

Geologic conditions.—The country rock is fine-grained blue Devonian limestone, underlain at a depth of 2,000 to 2,500 feet by white fine-grained quartzite. Both limestone and quartzite dip about 25° E. A dike of quartz diorite porphyry 45 feet wide extends N. 42° W. through the property, crossing the adit level 275 feet from the portal. It is also exposed in the upper workings, where it cuts across the vein. Very little if any alteration of the ore or of the limestone has been produced by the intrusion, although the weathered condition of the material precludes accurate determinations.

Two east-west open fissures, having a maximum width of about 5 feet but not averaging over 5 or 6 inches, have been encountered

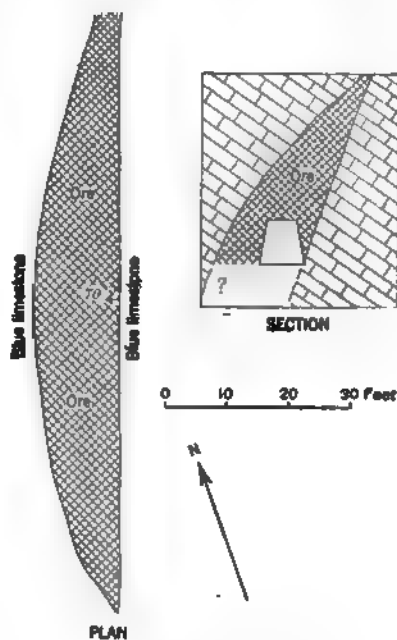


FIGURE 14.—Outline of ore body exposed in north drift, 100-foot level, Latest Out mine, Texas district. Shows the local lenslike form of the ore body both along the dip and the strike

in the workings and are clearly postmineral. In the big stope between the 100 and 200 foot levels, however, similar cross fissures represent points of maximum width in the vein and are evidently older than the deposits. They appear to be unmineralized beyond a few feet from the main ore body, a fact which suggests that, instead of carrying mineralizing solutions themselves, their intersections with the north-south channels merely afforded favorable places for replacement.

Ore deposits.—The ores of the Latest Out mine occur as irregular lenses along a rather poorly defined fissure which strikes a little east of north and dips about 70° W. (See fig. 14.) In the few places where grooves were noted they pitch about 50° S. Thus they occur

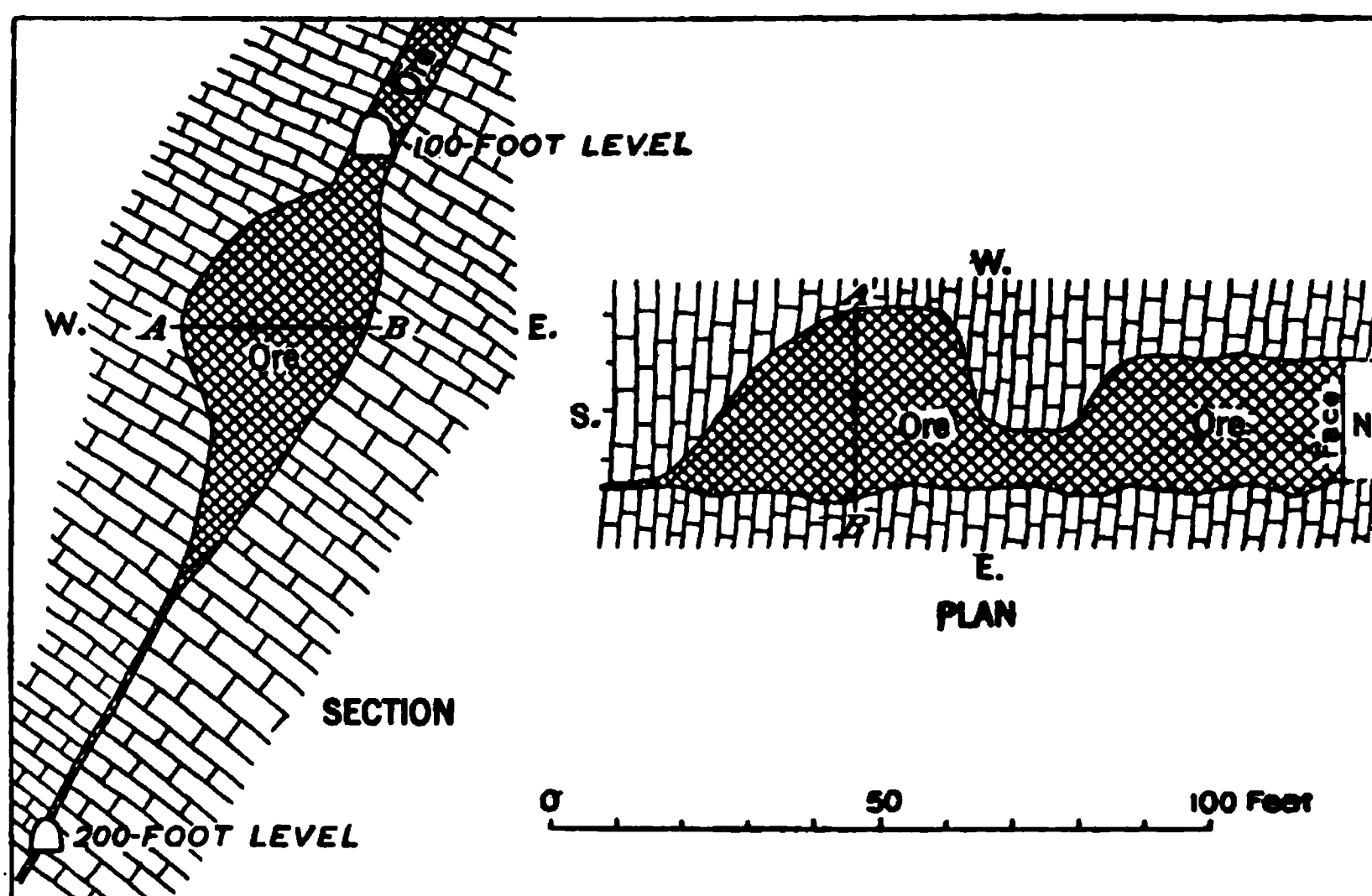


FIGURE 15.—Diagram illustrating replacement phenomena in Latest Out mine, back of incline between 100 and 200 foot levels. A-B is common to both the plan and the section.

in the south drift on the 100-foot level, where the walls are well defined but the fissure barren of ore. This relation of fissure and grooves is interpreted to mean that the ores occur along a fault, probably, however, one of minor displacement. In places the walls are in juxtaposition; in others, ground and crushed limestone fills the 3 or 4 feet intervening; and in still others, ore is the filling material. Much of the limestone adjacent to the vein contains isolated bunches of galena and rarely sphalerite, both of which from their position are clearly of replacement origin. (See fig. 15.) In most places, however, complete oxidation and carbonation have destroyed all the evidences of origin which ore usually discloses. As exposed at present the ore is an earthy iron and manganese stained material, mostly

incoherent. Fresh fractures show granular cerussite intimately mixed with iron oxide.

In general, the ore runs about 18 ounces in silver to the ton, 34 per cent lead, 10 per cent iron, and 5 per cent zinc.

ALLIE MINING CO.'S PROPERTY.

Situation and development.—The Allie Mining Co. owns 18 claims surrounding the Pittsburgh-Idaho and Latest Out properties at Gilmore. The group was located in 1903 and the present company organized in 1905. About 6,000 feet of development work has been done, principally on the Gilmore, Ruth, Glen, and Martha claims.

Ore deposits.—The extensive prospecting done by the company has not disclosed commercial deposits of lead-silver. Recently, however, a promising gold vein has been discovered on the Martha and Dorothy claims, and it is estimated that about 15,000 tons of ore, averaging about \$12 per ton in gold, are blocked out.

The ore, which is inclosed in flat-lying Devonian (?) limestone, occurs along a fractured zone, probably a fault plane, extending N. 10° E. and dipping about 20° W. It is developed from the Dorothy ground by a tunnel which taps it about 200 feet below the surface, and 228 feet lower it is reached by a crosscut from the 300-foot level of the Pittsburgh-Idaho mine. From the lower level a raise has been driven 175 feet on the vein and a vertical winze sunk 50 feet with crosscut to the vein. On several levels drifts extend laterally to the margins of the shoot, which as thus outlined averages 12 feet wide by 30 feet long.

The ore is an earthy iron and manganese stained mass, very soft, and in places showing casts of small pyrite crystals. Partial analysis shows 49 per cent iron oxide, 5 per cent silica, \$15 in gold, a trace of silver, and no lead. The total absence of lead and the comparatively high value in gold distinguish this vein from the other known deposits of the district. It is thought, however, that it was formed during the same period of mineralization as the lead-silver deposits.

Ore has been exposed on the Ruth claim, though not in commercial quantities. It is of interest chiefly in that it occurs along a well-defined east-west fissure. The fissure is filled mainly with gouge, through which the ore is sparsely scattered as small lenses and irregular bunches.

A promising claim of the Allie group is the Roy Sauer, which joins the Latest Out on the west. It is as yet unprospected, an incline shaft 20 feet deep being the principal opening. This extends down a fissure about 4 feet wide which dips 50° W. It contains heavy iron and manganese oxides and a little lead carbonate.

OTHER MINES AND PROSPECTS.

Numerous less-developed properties south of Gilmore are grouped below under the heading "Silver Moon and Liberty gulches," and others to the north under "Texas and Ulich gulches." Not many of them were visited. Two or three are of special interest as throwing light on relations in the district.

Silver Moon and Liberty gulches.—Silver Moon and Liberty gulches are deep narrow valleys which extend back into Lemhi Range from points about 3 miles and 1 mile, respectively, south of Gilmore. In Liberty Gulch several hundred feet of development work has been done. In Silver Moon Gulch most of the deposits strike north and south with the limestone but dip west, almost at right angles to the dip of the latter. The Silver Moon vein is an exception in that it lies with the bedding of the inclosing formation. This vein differs also from the others in being predominantly a silver instead of a lead deposit. The Silver Moon ore body, as exposed in the tunnel level, is in the form of a lens about 50 feet long and 30 inches in maximum thickness, feathering out to the north and south. The vein is said to have produced about 80,000 ounces of silver during its period of activity, 20 or more years ago.

Other properties in the gulch produced a little lead-silver in the early days of the district. Chief among these are probably the Grace Phelan and Hecla groups.

Texas and Ulich gulches.—Texas Gulch, from which the Texas mining district derives its name, is situated about 2 miles north of Gilmore, and extends back into the mountains for several miles as a deep flat-bottomed canyon. Its principal properties are the Mountain Boy and Portland, neither of which was visited.

Several properties are situated in Ulich Gulch, one-fourth mile farther north, but only two—the Jumbo and the Democrat—were visited. The Jumbo deposit is opened by tunnel and incline shaft, all together constituting perhaps 800 to 1,000 feet of development. The inclosing limestone strikes N. 20° E. and in general dips east, although there are many local variations to the west. A diorite dike about 12 feet wide follows the strike of the limestone and dips 70° to 85° W. This deposit is of special interest in that it reveals, more conclusively than any of the others visited, the replacement phase of the lead-silver deposits. Stringers of galena and cerusite following joint planes here and there merge into irregular lenses of ore which extend for several feet along the bedding; in some places both ways from a given joint, in others in but one direction, either up or down the dip (fig. 16). Many of these lenses are made up of unaltered material, but some are composed entirely of secondary minerals. About 400 tons of ore running 37 per cent lead, 48 ounces in silver, and \$3.50 in gold have been shipped from the property.

Near the mouth of Ulich Gulch is the Democrat mine. It was staked in 1880 and is said to be the earliest located in the district. The vein, which is wide and persistent, corresponds in strike to the inclosing limestone. Both dip east, the vein 70° and the limestone about 45° . The gangue is very siliceous, carrying galena and pyrite, together with minor amounts of derivatives from them. The ore is said to contain about 9 per cent lead and 4 ounces in silver.

BLUE WING DISTRICT.

SITUATION AND HISTORY.

The Blue Wing mining district comprises a small area along the middle and headwaters of Patterson Creek, a stream draining south to Pahsimeroi River from the crest of Lemhi Range. It is 20 miles southwest of Leadore, Idaho, which will be the outlet when a wagon road, now in course of construction, is completed over the range. Prospecting within the district has centered about Ima, a small settlement 2 miles above the mouth of Patterson Creek canyon.

Mineral locations were made near Ima as early as 1881, but active developments did not begin until 1900, when the Ima Consolidated Mining & Milling Co. started exploratory work which continued during the four succeeding years. Tungsten was first recognized in 1903, but not until the spring of 1911 did it attract serious attention. About this time the Idaho Tungsten Co. was formed and secured a seven-year lease on the 21 patented claims owned by the Ima Co. Subleases have been let to two or three companies and new locations made by individuals.

A 50-ton capacity concentrating mill has recently been installed, it being the plan to produce a 60 per cent concentrate for shipping. Developments consist of four or five tunnels and an incline shaft 75 feet deep; in all, perhaps 2,000 feet of work. The lower tunnel enters the west wall of the canyon near the creek level and the others extend in the same direction at irregular intervals above. The first above, which is known as No. 4 tunnel, is 900 feet long.

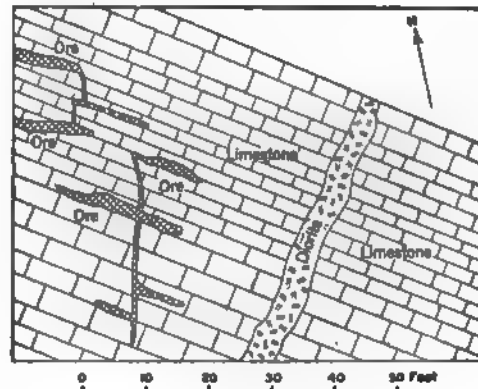


FIGURE 16.—Sketch illustrating occurrence of ore and geologic relations in Jumbo mine, Texas district. Diagrammatic in part.

GEOLOGIC RELATIONS.

The deep, narrow canyon of Patterson Creek is cut across a prominent anticline which reaches from the canyon's mouth to the forks of the stream 2 miles above. At the lower point the beds incline 40° to 90° W., and at the upper they dip almost as steeply in the opposite direction. The rocks are quartzitic slates and schists with a little sericitic and chloritic schist, and succeed one another in monotonous succession. They are of Algonkian age, probably representing the upper members of that series.

No igneous rock outcrops in the immediate vicinity of the mines. Boulders of quartz diorite along Patterson Creek, however, support the statement that an igneous mass appears at the surface a short distance up the west fork.

ORE DEPOSITS.

The principal mineral deposits now known cross Patterson Creek about a mile above the mouth of its canyon. From the creek level, it is said, the veins outcrop at intervals to the west rim of the canyon, 2,200 feet higher. They follow fractures which in general parallel the anticlinal axis, running N. 30° to 40° W., but locally digress 20° or more. The dip of the veins is usually 50° to 70° SW. They vary in width from stringers to 10 or 12 feet, and in one place in the lower tunnel to 20 feet. The vein filling is coarse-textured, bluish quartz, extensively crushed by postmineral movements. Its contact with the hanging wall is usually sharp, although many stringers extend out into the country rock, and in places several parallel veinlets accompany the main vein. The foot wall is locally less clearly defined, quartz being intermixed with crushed wall rock.

Scattered rather sparsely and very irregularly through the coarse white quartz are crystals and irregular areas of sphalerite, tetrahedrite, pyrite, hübnerite, galena, molybdenite, and chalcopyrite. These are clearly of primary origin, but in addition to them are a considerable number of minerals which, from their occurrence along fracture planes, in cavities, and near the outcrop, are thought to be secondary. Among them limonite, malachite, azurite, and manganese oxide are common, and cerargyrite, bornite, chalcocite, cuprite, siderite, possibly molybdenite, and scheelite are comparatively rare. Following is a list of the minerals seen in the deposit, with notes on their peculiarities and occurrence.

Azurite.—The blue copper carbonate occurs as stains in the oxidized ore.

Bornite.—The purple copper-iron sulphide occurs closely associated with chalcopyrite in partly oxidized ores.

Cerargyrite.—Silver chloride appears in the oxidized zone as one of the products in the breaking down of tetrahedrite. It occurs as green and gray crusts.

Chalcocite.—Copper glance is found in some of the oxidized ore.

Chalcopyrite.—The primary copper-mineral chalcopyrite occurs as small, irregular patches in the firm quartz.

Cuprite.—The red copper oxide is rare.

Galena.—Lead sulphide occurs as fine-grained masses and rarely as small cubes. It is not conspicuous in the ore.

Hübnerite.—Manganese tungstate is the chief ore of tungsten in the district. The variety here found contains 2 per cent of iron oxide and about 76 per cent of tungsten trioxide. It occurs embedded in the quartz either as reddish-brown masses or crystals and is likely to be confused with the peculiar type of sphalerite found here. The two may be distinguished easily, however, by scratching a smooth face, the latter giving a gray streak readily distinguished from the brown streak of hübnerite.

Limonite.—Limonite is abundant near the surface and occurs in a great variety of shades from almost red to lemon-yellow.

Malachite.—The green copper carbonate is locally conspicuous in the oxidized ore.

Manganese oxides.—Manganese oxides occur in a variety of forms from black powder to dendrites and beautiful aggregates of radiating prismatic crystals. (See Pl. XIII, A, p. 72.)

Molybdenite.—Molybdenum sulphide occurs as sheens on fracture planes, as thin foliated masses lining small crevices, and as scales and small grains intergrown with the primary ore minerals.

Pyrite.—Pyrite occurs as small cubes and irregular patches embedded in the quartz.

Scheelite.—Calcium tungstate is not important in the deposits. It occurs as pale-yellow grains in the powder which locally fills crevices in the ore and rarely as small druses in cavities near the surface.

Siderite.—Carbonate of iron occurs as very small platy crystals covering fracture faces. (See Pl. XIII, B, p. 72.) They vary from dark brown to straw color. Many of the plates stand on edge.

Sphalerite.—Zinc blende, almost black in color, is common in the ores and is likely to be confused with hübnerite. Its characteristic light-gray streak affords an easy means for field identification.

Tetrahedrite.—Gray copper is abundant locally as irregular masses of peculiar greenish color. Partial analysis by R. C. Wells, of the Survey laboratory, reveals 1.9 per cent of silver and 29.7 per cent of copper.

The most striking feature brought out by a study of ore specimens from the Blue Wing district is the absence of definite sequence in the formation of the constituent minerals. Only one period of mineralization is recorded. In some places hübnerite occurs with distinct crystal outlines indicating that it was first to form; in others, however, it is so intimately intergrown with sphalerite that their essential contemporaneity can not be doubted. The two are frequently in contact and bear the same relation to the inclosing quartz. In places sphalerite includes pyrite, molybdenite, and tetrahedrite. Elsewhere pyrite includes the last two and probably also chalcopyrite. Galena seems to be contemporaneous with sphalerite. (See Pl. XIII, C, p. 72.)

Most noteworthy of the above relations is the intimate association of tungsten and zinc, which are uncommon in the same deposit elsewhere, and which, so far as the writer is aware, have not been described before as resulting from the same period of mineralization.

The mineral veins at Ima are of pre-Eocene age, for they were truncated by Eocene erosion. Only two periods of metallization have been recognized in this part of Idaho, one late Cretaceous or early Eocene and the other Miocene or early Pliocene. These deposits are assigned to the former.

The unusual number and variety of essentially contemporaneous minerals in the deposit indicates very complex mineral-bearing solutions. No less than twelve elements were present, and presumably several others. The structure of the ore indicates an aqueous solution which acted in open fissures and crevices. It produced little change in the wall rock. The state of combination of the several elements in the solution is not known, but of the minerals resulting from it hübnerite was locally the first to form. The several other minerals are mutually intergrown and included in coarse granular quartz. The deposits are thought to be genetically related to the quartz diorite which outcrops at several places along the Lemhi Range.

JUNCTION DISTRICT.

SITUATION AND HISTORY.

The Junction mining district comprises an ill-defined area of several townships, centering about a point a few miles northwest of the town of Junction in the southeast part of Lemhi County. It may be considered as extending northwest to the McDevitt district (which is definitely bounded by Reese Creek), northeast to the Continental Divide, and southwest to the summit of Lemhi Range. To the southeast the district merges into country from which mineral has not been reported.

The district is crossed by the Gilmore & Pittsburgh Railroad. Excellent wagon roads lead to Salmon, 50 miles northwest, and to Gilmore and Dubois, respectively 17 and 100 miles to the south and southeast.

Although mineral has been known in the Junction district for a number of years, it may be considered one of the younger districts in the county, the principal location having been made in 1904. Active development began on the Leadville mine in 1905 and most of the prospecting in the surrounding country has been done since that date.

The Leadville mine, which is the only producer in the district, made its first shipment in February, 1908. Its total production is about \$75,000 in lead and silver bullion.

TOPOGRAPHY.

The Junction district comprises a segment across the broad valley of Lemhi River at a point where its course changes from north to northwest. On the northeast the valley side rises to an elevation of about 8,000 feet or 2,000 feet above the valley, and on the south-

west abrupt slopes lead up to an elevation of 10,000 feet. The central valley has a gently sloping floor from 6 to 15 or more miles in width. Peterson, Little Eightmile, and Canyon creeks flow through deep narrow canyons which extend back to the crest of the Beaverhead Mountains, the last named forming Bannock Pass, one of the most accessible gateways through the divide. On the southwest side of the valley, Mill, Lee, Eightmile, and Timber creeks occupy similar canyons, which lead from the Lemhi Range.

• GEOLOGY.

Along the northwest side of the Lemhi Valley at the base of the range the older rocks were examined at several points, but the opposite side of the valley was not visited. As thus encountered they presented a succession of limestones, slates, and quartzites, named in descending order of importance. In general they strike N. 30°–50° E. and dip 30°–50° SE., although locally wide departures from these values occur.

A great succession of Miocene lake beds occupies the broad Lemhi Valley. No local information was obtained concerning their maximum thickness, but if the general history of the formation has been interpreted correctly (see p. 35) they probably extend to a depth of 2,000 feet or more.

Faulting is evident along the northeast margin of the valley, where for about 5 miles prospects are distributed along a mineralized displacement plane which dips about 40° SW. and throws Miocene lake beds against the older rocks.

Both intrusive and extrusive igneous rocks occur in the area, the latter being confined to its northwest part. Near Junction a light-gray porphyritic rock about the composition of granite is found. A dike of this rock, best designated as granite porphyry, extends along the lower slopes of the range to the northeast. As float of similar material was noted in the canyons above their intersection with this dike, it is probable that other dikes occur farther up the mountain slope.

The canyon of Little Eightmile Creek near its mouth is cut in a dark-gray fine-grained holocrystalline rock composed of plagioclase (about oligoclase), quartz, biotite, and hornblende, with a few crystals of orthoclase. It is classed as quartz diorite. The mass is laccolithic or batholithic in outline, about 300 feet vertical being exposed in the canyon sides. A similar intrusive quartz diorite occurs about 3 miles from the mouth of Eightmile Creek canyon in the Lemhi Range.

Effusive rocks appearing as boulders along the side terraces of the Lemhi Valley in the vicinity of Little Eightmile Creek are predominantly dark-gray andesite composed of plagioclase crystals sparsely studding a glassy to microcrystalline groundmass. Subordinate in

amount to the andesite is a bluish-gray rhyolite composed of orthoclase, biotite, and quartz phenocrysts in a glassy groundmass.

From the local area little can be said concerning the age of these rocks.

ORE DEPOSITS.

Mining claims have been located in the mountainous areas on both sides of the Lemhi Valley, but those most important at present are confined to a narrow zone along the northeast margin. (See Pl. XVI.) The ore deposits crop out between elevations of 6,500 and 7,000 feet.

Near the town of Junction the prospects and mines are distributed along a fault plane which probably served to direct the mineralizing solutions. Later movement has taken place along this fault with the result that now unmineralized lake beds form the hanging wall of the ore bodies, being separated from them by a thin gouge seam consisting of clay and in a few places of pulverized ore. The line of prospects extends for about 5 miles northwestward from the mouth of Canyon Creek gorge. This occurrence of a vein between a footwall of Paleozoic rocks and a hanging wall of comparatively recent lake beds is unusual but not unknown in the literature. The Curlew vein near the north end of the Bitterroot Range is probably of the same age as this one and has a hanging wall of Pleistocene gravels.¹

Other mining claims are located about the canyon occupied by Little Eightmile Creek and its tributaries. These are inclosed in slates and limestones, adjacent to a base of quartz diorite.

The only property with sufficient development to afford conclusions concerning the ores is on the Leadville claim of the Junction Mine Co.'s group. In this property the predominating ore is fine-grained argentiferous galena, usually remarkably free from gangue. Many small amounts of pyrite appear in the deposits and in a very few places a little chalcopyrite. The better grade of ore runs from 50 to 60 per cent lead and 28 to 35 ounces of silver per ton.

Two ore shoots occur in the deposit, the ores of which differ somewhat in composition, as shown by smelter analyses, although in the hand specimen no mineralogic difference is evident. The analyses follow:

Analyses of ores from Leadville mine, Junction district.

	Gold.	Silver.	Lead.	Cop- per.	Insol- uble.	Zinc.	Sul- phur.	Iron.	Arsenic, antimony, and bismuth, not separated.
No. 1 shoot.....	Tr.	35.0	56.5	0.2	16.0	.....	9.8	2.8	.....
No. 2 shoot.....	Tr.	28.8	54.5	.2	15.0	1.0	11.0	2.0	.....

¹ Lindgren, Waldemar, A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: Prof. Paper U. S. Geol. Survey No. 27, 1904, p. 86.

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From the amount of sulphur contained in both shoots it is obvious that the ore is primarily in the form of sulphides. Copper is negligible, as are also zinc and gold. Iron, although present in noteworthy amounts, is much less conspicuous than in the deposits of the Texas district to the south. The relative amounts of antimony, arsenic, and bismuth are not known; neither is their mineralogic form, although it is very probable that the first two are combined with silver as sulpharsenite and sulphantimonite. Bismuth is not common in such deposits and it is not possible to infer its combinations with any degree of certainty.

Ground-water level occurs at different elevations on opposite sides of the granite porphyry dikes which parallel the range near its base. That the lower elevation prevails on the side toward the Lemhi Valley is obvious from the prevalence of springs at low points in the dikes. Canyon Creek, which derives most of its waters from springs on the upper side of a granite porphyry dike crossing the canyon near its mouth, is a case in point. West of the dikes the position of the water table is determined by the elevation of Lemhi River in the valley opposite, allowing a reasonable gradient toward the river. East of them its level is determined by the point of intersection of the adjacent canyons and the dike.

Along the fault which forms the hanging wall of the deposits near Junction a seam of very impervious clay gouge has protected the ores from descending oxygen-bearing waters, so that they in general retain their primary mineralogic constitution to an extent uncommon above ground-water level elsewhere in the lead-silver deposits. This preservation is probably conditioned by the flat attitude (35° dip) of the fault plane, although another factor may be the small amount of pyrite in the deposit, it having been shown by experiment that the presence of pyrite tremendously facilitates the oxidation of lead sulphide.¹ As the 2 per cent of iron (principally pyrite) in the deposits is sufficient to afford considerable ferric sulphate, the relative importance of this factor is not obvious.

MINES.

LEADVILLE MINE.

The Leadville mine is situated in the southeastern part of Lemhi County, 3 miles northeast from Junction and about half a mile from the Gilmore & Pittsburgh Railroad, on the margin of the valley flat traversed by that line. The property was located in June, 1904, but active development did not commence until a later year. Ore shipments, which continued regularly until the summer of 1911, began in February, 1908. In the early summer of 1911 there was a change of

¹ Buehler, H. A., and Gottschalk, V. H., Oxidation of sulphides: *Econ. Geology*, vol. 5, 1910, pp. 28-35.

management and the period since has been principally spent in development.

The property is developed by two tunnels and a shaft which reaches levels intermediate between them. The upper tunnel is 500 feet long, starting from a point above the shaft. The lower tunnel enters the hill near the level of the valley flat reaching the vein 876 feet from the portal and at a depth on the lode of 510 feet. The main opening at present is a single compartment shaft with drifts totaling 900 feet on the 65 and 110 foot levels.

Since 1908 the property has produced about \$75,000 in lead and silver bullion.

The country rock of the Leadville group comprises both later Paleozoic sedimentary rocks and Miocene lake beds. The older rocks consist of limestones, quartzites, and quartzitic slates which strike N. 70°–80° E. and dip 35° SE., thus corresponding in attitude to the veins. Overlying these unconformably are the lake beds which occupy the broad valley of Lemhi River; they are composed of detrital material largely from the hills adjacent. As exposed at the surface and within the mine the contact between them and the older rocks is a fault plane. (See fig. 17.) That the fault occurs near the margin of the lake in which the younger beds were deposited is clearly shown by a section along the lower tunnel of the Leadville mine. In the outer part the material is well sorted and stratified, but within the last 200 feet near the fault it grades into heterogeneously arranged and poorly sorted fragments, indicative of a talus-like accumulation near the margin of the lake. Throughout, the material is firmly cemented and presents little evidence of disturbance since its original deposition.

General quiescence since their formation is recorded in the slightly fractured condition of the ore bodies, although the limestone in which they occur is extremely crushed for a few feet next the fault. As the gouge next the lake beds contains fragments of ore and the principal brecciation of the limestone seems to be older than the ore, it is thought there have been two periods of movement along the vein fissure, one prior to the ore deposition and the other comparatively recent.

A single granite porphyry dike was noted, which cuts the older series and is about parallel with it in strike but stands more nearly vertical; others doubtless occur.

The Leadville deposits contain lead-silver ore, remarkably free from other metals. They occur as replacements in limestone along the footwall of an old fault, the hanging wall of which has moved down relatively, bringing Miocene sediments into juxtaposition with the ores. The thin seam of red clayey gouge accompanying the recent movement contains fragments of galena, especially in sections

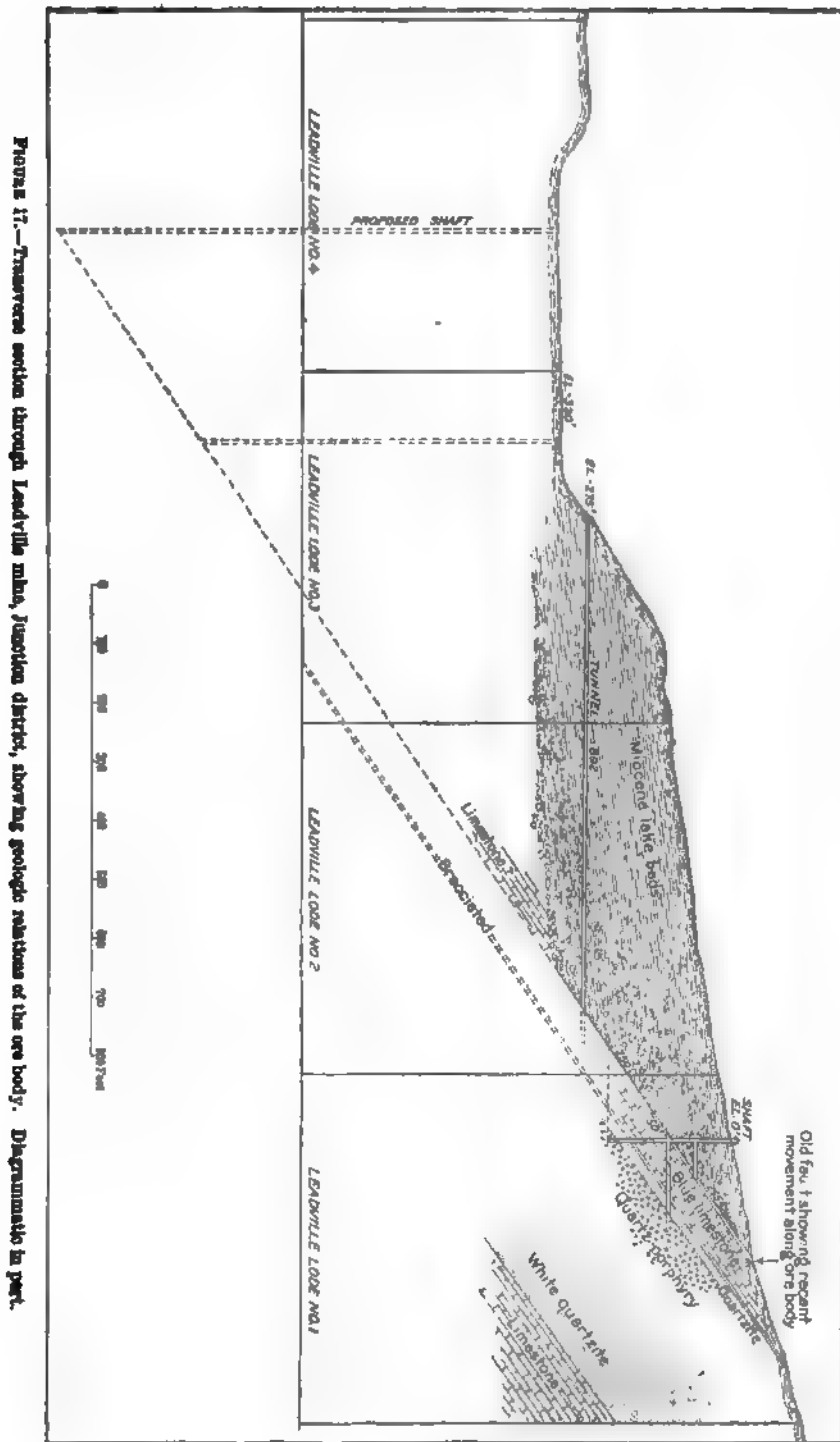


FIGURE 17.—Transverse section through Leadville mts., Junction district, showing geologic relations of the ore body. Diagrammatic in part.

opposite to and below ore bodies, and although they are in few places sufficiently numerous to constitute an ore, their presence is considered indicative of an ore body adjacent to and up the fault from the place where they are found. In general the replacement bodies are tabular in outline and closely parallel to the fault plane with which they are in many places in contact.

Two ore shoots, separated by about 40 feet of barren crushed limestone, are recognized in the mine. The shoots are respectively 180 and 110 feet long on the 110-foot level and 80 and 60 feet long on the 65-foot level, the larger body being the western or No. 1 shoot. Both reach to the upper tunnel level. In No. 1 the ore ranges from 2 inches to 2 feet in width, and in No. 2 it ranges from scattered crystals up to 4 feet of galena. No. 2 shoot differs from No. 1 in being more oxidized, containing less lead, silver, and iron, and having an appreciable amount of antimony, arsenic, and bismuth. Even here, however, oxidation is inconspicuous.

Mineralogically the ore is predominantly fine-grained galena (steel galena), with pyrite not uncommon and sphalerite and chalcopyrite very rare. The mineralogic form of the antimony, arsenic, and bismuth is not known, although they may very well be constituents either of lead or of silver minerals. Limited amounts of cerusite, anglesite, and limonite occur in the deposits. Analyses of the ore from the two stopes appear on page 65.

The better-grade ore gives a gross return of \$50 to \$65 a ton.

OTHER PROPERTIES.

Claims are located for 5 miles along the fault which accompanies the Leadville ores, but all of them are still in the early prospect stage. Even though ore has not been found in commercial quantities in any of these properties, their occurrence in a mineral belt and with geologic relations analogous to those prevailing at a near-by producing property should encourage a reasonable amount of exploration. Claims are also situated on Little Eightmile Creek, where, although large ore bodies have not been found, the general relations are such as to justify careful prospecting and a reasonable amount of exploration.

McDEVITT DISTRICT.

GENERAL FEATURES.

The McDevitt district, the only organized mining district in Lemhi County, lies about 20 miles southeast of Salmon. It embraces a section across the Lemhi Valley from the crest of Lemhi Range northeast to the summit of the Continental Divide, and extends from Haynes Creek 17 miles southeast to Reese Creek. The Gilmore & Pittsburgh Railroad and an excellent wagon road traverse the district along the Lemhi Valley. The old stage line from Red Rock,

Mont., to Salmon enters near the head of Agency Creek, the principal tributary to Lemhi River from the northeast.

The district includes the Lemhi Indian Reservation, which was thrown open to mineral entry July 15, 1909. Immediately after its opening about 35 claims were staked, principally along McDevitt Creek. The only property that has produced, however, is just beyond the reservation boundary to the northeast, and is a mine—the Copper Queen—which was located in April, 1883, and has been operated intermittently since 1905. The total production of the district is probably a little less than \$100,000.

TOPOGRAPHY.

The mountain slopes, which rise from the margins of the broad valley of Lemhi River, attain within short distances heights of 8,000 to 9,000 feet above sea level, or 2,000 to 3,000 feet above the valley. The streams tributary to Lemhi River occupy deep narrow gorges in the mountains, but on reaching the lowlands they follow comparatively shallow open depressions. Of these streams, Payette, Agency, and Yearian creeks enter from the northeast and Haynes, Baldy, McDevitt, Muddy, and Hayden creeks from the southwest.

GEOLOGY.

The sedimentary rocks of the district are of Algonkian, late Paleozoic, and Miocene age. The contact between the two older formations extends in a northeast-southwest direction and lies between Yearian and Agency creeks, although its exact position was not determined. To the southwest the contact is probably concealed by the broad belt of late Tertiary lavas which extend in that direction. The Miocene beds occupy the Lemhi Valley and extend up its sides to an elevation of about 7,000 feet.

The Algonkian rocks consist of greatly fractured massive dark siliceous slates and gray quartzites, which are readily distinguishable from the limestone, white quartzites, and thinly cleavable slates of the Paleozoic. Presumably the Algonkian and the Paleozoic are separated by a strong structural unconformity, although the exposures visited did not afford definite evidence to that effect. Each is highly tilted, the dip varying markedly from place to place, both in direction and angle. In general, however, the dips seem to be 30° to 50° W. The lake beds are made up of stratified gravels, sands, and clays, the first being most pronounced near the margins of the basin in which they lie, and the last conspicuous in the bluffs along Lemhi River. Intermixed with the clastic material, though in places occurring in fairly pure bands, is volcanic tuff. The thickness of the lake beds is not definitely known, but they are probably to be measured

in hundreds, perhaps thousands, of feet, if the interpretation of conditions existing during their formation, as outlined on page 35, is correct.

Basalts and rhyolites are widely distributed throughout the district, and along Agency Creek dikes of similar composition were noted. Because of lack of time the boundaries of the lavas were determined in only a general way. From the head of Agency Creek they extend in a southwesterly direction across the Lemhi Valley and are distributed along the east face of the Lemhi Range throughout the entire length of the district. From the aspect of the topography high up on that range, it is thought that they cross the summit in places, possibly connecting beyond with the lavas along Salmon River. The two types of eruptives may be readily distinguished, for the basalts are fine-grained bluish-black rocks, in many places rusty on weathered surfaces, whereas the rhyolites present various shades of gray, commonly with conspicuous flow lines.

That the lavas are very young is suggested by their generally well-preserved vesicular structure, and confirmed by their occurrence as caps on some of the intermediate terraces developed in the Miocene lake beds by Lemhi River.

ORE DEPOSITS.

Mineral locations in the district are largely grouped about the headwaters of Agency Creek and along McDevitt Creek. Only those about the former, which include the Copper Queen mine, were visited. The Copper Queen is the only property developed beyond the early prospect stage.

COPPER QUEEN MINE.

The Copper Queen Gold Mining Co. holds a group of 12 claims on the south fork of Agency Creek, 3 miles west of the Idaho-Montana line. The property was located in April, 1883, by F. B. Sharkey and George Chamberlin, but was not operated until leased in 1905 and 1906. In the latter part of 1906 it was secured by a Duluth company, which sank a 400-foot shaft and did considerable drifting on the 120, 200, and 400 foot levels. This work and four little tunnels which enter the hill on the opposite side of the gulch at vertical intervals of about 100 feet, give a total of perhaps 2,500 feet of development.

The production consists of 480 ounces of gold secured with a 5-stamp mill and the returns from 18 cars which averaged 28.3 per cent of copper and 6 ounces of silver and \$24.75 in gold to the ton. In addition to these amounts some gold was extracted during the early days of prospecting, perhaps sufficient to raise the total production to \$100,000.

The property has been recently acquired by the present owners, who purpose to put in a concentrating mill and work the lower-grade ore which remains in many of the old stopes.

The veins are inclosed in quartzites and quartzitic slates, which, though varying widely in places, in general seem to strike about N. 70° E. and dip 40°–70° NW. The principal vein follows approximately the inclosing rock in strike but is said to be independent of it in dip. Above a point 152 feet below the surface (level of water at time of visit), the vein dips 40°–70° NW., but below it bends back, dipping steeply southeast. The vein is from a few inches to 9 or 10 feet wide, averaging about 3½ feet where it has been stoped. The walls are sharply defined and the hanging is very regular, although the opposite side presents many swells and hollows. Included in the quartz are many fragments of wall rock, some of them slabs several feet in length.

The gangue is a white, coarsely crystalline quartz, in places granular in appearance and in places containing a sparse intermixture of small bunches of calcite. Metallic minerals are distributed through the gangue without apparent regularity, in some places the quartz being free from metallization and in others the ore minerals predominating. Important among the ore minerals are bornite, a little chalcopyrite, chalcocite, specks of free gold, in a few spots a little cuprite, and at the surface much malachite and a little azurite. The chalcopyrite is clearly primary and in places the manner in which the bornite is included in the quartz suggests that it also may be primary, but so general is the oxidation throughout the accessible workings that this can not be certainly determined.

The better ore occurs in irregular shoots, which vary markedly in richness from place to place. In the past only the richer portions have been worked, but it is now planned to handle the considerable tonnage of intermediate grade which bounds the old stopes.

PRATT CREEK DISTRICT.

The Pratt Creek district lies 15 miles southeast of Salmon, about the headwaters of Wimpey and Pratt creeks. It includes a belt some 6 miles wide, extending from Lemhi River northeastward to the base of the mountains, and thence up their rugged slopes to the crest of the Beaverhead Mountains, the elevation in the last 5 miles increasing about 4,000 feet.

The geology is simple. Miocene lake beds occupy the lowland up to 6,500 feet, above which are Algonkian sedimentary rocks. The older rocks strike a few degrees west of north and dip from 10° to 85° W., commonly 45° to 50° W. As seen near the mouth of Pratt Creek canyon in a vertical face possibly 700 feet high, the series is made up of alternating layers of quartzites, quartzitic slates, and some schists, each in beds from 1 foot to 5 feet thick. Traversing these are a few bands of basic diorite, nowhere well exposed, but to judge from the distribution of float, locally more than 100 feet thick.

Mineral locations in the district comprise one mine and a few undeveloped prospects. As the deposits visited showed similar structure and composition, it will suffice to describe the Goldsmith mine. Mention should be made, however, of the Dark Horse property, situated 2 miles north of the Goldstone mine on the Montana side of the divide. Here about 4,000 feet of work has been done, though little ore has been developed. Some 2,400 feet of the work consists of a rock tunnel, not yet completed, through the divide from Montana to Idaho. The purpose of the tunnel, it is said, is to afford means for marketing ore at Baker, Idaho.

The Goldstone mine, now owned by the Climax Gold Mining & Milling Co., is situated on Pratt Creek 1 mile west of the Idaho-Montana line, at an elevation of about 9,200 feet above sea level. Baker, Idaho, 12 miles distant, is the supply point. The property was located in the early nineties and has changed hands several times. In 1896 and 1897 a 10-stamp mill was erected and has treated perhaps 1,000 tons of ore. Development consists of a 235-foot shaft and about 3,000 feet of tunneling.

The vein, inclosed in chloritic schist and quartzite, strikes N. 62° W. and dips 75°–85° NE. The hanging wall is sharply defined, but many stringers of vein matter extend into the footwall. The vein is a quartz filling from a few inches up to 4 feet in width and locally includes many fragments of wall rock. Scattered through the quartz are chalcopyrite, its oxidation products, and galena. Gold, for which the property is held, is said to vary directly with the percentage of copper in the ore.

ELDORADO DISTRICT.

SITUATION.

The Eldorado district lies about 9 miles east of Salmon and includes a short section of the western slope of the Continental Divide and the adjacent part of the Lemhi Valley. It is named after the Eldorado mine, a property of local prominence about 30 years ago. Interest in the area centers, however, about the placers of Bohannon Bar, which were worked in the early days by Chinamen and which have furnished by far the larger part of the \$400,000 credited to the district as a whole.

TOPOGRAPHY.

The district embraces a belt of country about 6 miles wide extending northeastward from Lemhi River to the crest of the Continental Divide. From the river, at an elevation of 4,500 feet, the surface rises gently for the first 6 miles, beyond which precipitous slopes lead to the crest of the range, 9,500 feet above sea level. The principal streams are Geertson and Bohannon creeks, which flow in deep narrow canyons in their upper parts but occupy broad open valleys as they cross the lowlands to their junctions with Lemhi River.

GEOLOGY.

The older sedimentary rocks are Algonkian schists, quartzitic slates, and quartzites. In general they strike a little west of north and dip west. Overlying these strata in the southwestern half of the district are thick Miocene lake beds composed of detrital material from the near-by mountains. In general the lake beds are distinctly stratified, and in the floors of shallow valleys cut in them are long tongues of gravel washed down by Geertson and Bohannon creeks. It is in the gravel beds that the placer gold is found.

Many boulders of a dark-gray fine-grained igneous rock appear along Geertson Creek. In thin sections of this rock small orthoclase and hornblende crystals are visible in almost equal amounts. A little micropegmatite is present, and there is a slightly phenocrystic development of quartz. The rock is classed as a quartz-bearing vogesite.

VEIN DEPOSITS.

The Eldorado and Ranger are the principal vein deposits. Both are situated on the mountain slope at elevations of about 8,800 feet. Only the Ranger mine was visited, but ore from the Eldorado mine, seen along the old tram line, is in every respect similar. The Ranger vein occurs along a shear zone whose firm walls are generally about 5 feet apart. Between them gouge and brecciated country rock include lenses, stringers, and irregular bodies of quartz. Scattered through the vein material are pyrite, chalcopyrite, and rarely a little galena, together with their oxidation products, with here and there a speck of native gold.

The properties were worked many years ago, the ores being treated in a 20-stamp mill situated a short distance down the canyon. The production was probably moderate.

PLACER DEPOSITS.

The important placer of the district is Bohannon Bar. It includes a narrow belt along Bohannon Creek, between the base of the mountains and Lemhi River. The bar was worked by Chinamen as far back as the early seventies, but not until acquired by the present owners in 1895 did its active development begin. Since then about 150 acres have been washed. Water is gathered from several canyons along the range and stored in a large reservoir, thus affording an abundant supply for operating a 6-inch giant.

The auriferous gravels occur in three benches and range in thickness up to 14 feet south of the creek and 31 feet north of it. The two lower benches have furnished most of the production, although at present the rim of the upper one is being worked. The deposit consists of round boulders, generally less than a foot in diameter, with sand and gravels loosely filling the interstices.

The bedrock is an even floor cut across rather sharply tilted shales, sandstones, and conglomerates of Miocene age which dip 22° NE. The 5 feet of gravel lying directly above bedrock carry most of the gold, the lower 18 inches being the more productive. The gold is worth about \$18.60 an ounce and occurs as coarse flakes, fine grains, and rarely as small nuggets. It is claimed that on a broad average the ground runs about $13\frac{1}{2}$ cents a yard, although some pits give as high as 23 and 25 cents. The total production of the placers is said to be about \$350,000, the present annual output varying from \$15,000 to \$20,000.

KIRTLEY CREEK DISTRICT.

GENERAL FEATURES.

The Kirtley Creek district lies a few miles east of Salmon, between the Eldorado district on the south and the Carmen Creek district on the north. It includes a strip of country 5 or 6 miles wide, extending from Lemhi River northeastward across the lowlands to the base of the mountains and thence up their rugged slope to the summit. Kirtley Creek, a tributary to Lemhi River, 3 miles above Salmon, drains the area. Placers long known along its lower course have recently attracted serious attention, and lode deposits at its head have produced some bullion.

The formations are similar to those in the Eldorado district (see p. 122), and hence will not be described again here.

LODE DEPOSITS.

The White Horse mine is situated at an elevation of 9,100 feet on the north side of the large cirque at the head of Kirtley Canyon. It was located in 1899 and worked by an arrastre for three years following, when a 5-stamp mill was built. The recovery from the early treatment is not known, but about 900 tons of ore averaging \$45 a ton in gold are said to have been reduced by the mill.

The vein is very similar to the Ranger vein of the Eldorado district and may, indeed, be its northward continuation, for the two are in line and only half a mile apart. The vein strikes north and south and dips 35° – 40° W., for short distances up to 85° W. Jumps from one set of fractures to another and rolls give local variations to the east. The vein is very irregular in width, in few places reaching more than 15 inches in a clean band. In places, however, as much as 3 feet of quartz appears distributed through a face of 7 or more feet wide. The quartz is coarse textured, and scattered through it in buncy arrangement are pyrite and chalcopyrite and a little galena. In the ores now worked the oxidation products of these minerals, together with a few specks of free gold, constitute the principal minerals.

The same vein appears in the head of the cirque on the Smith claims and in the south wall of the cirque on the Confidence claim, and southward it may continue as the Ranger vein, Eldorado district.

PLACER DEPOSITS.

Placers, worked on Kirtley Creek from 1890 to 1894, were abandoned until the spring of 1910, when a California dredging company took an option on the ground and had it carefully prospected. As a result about 400 acres of placer ground, of sufficient value to warrant the installation of a dredge, has been developed; and a dredge of 9 cubic feet capacity is now in course of construction. The deposits are recent gravels along Kirtley Creek and extend for 5 miles below the mouth of the canyon. Some gold has also been found in the Miocene lake beds near their junction with the mountain slope, but the attempt to work these where they appear in the valley sides above the younger deposits was soon abandoned. The lower (younger) bed averages about 17 feet in thickness and is made up of waterworn boulders and pebbles of quartzite, slate, and schist, in most places loosely cemented by sand and clay. The boulders range up to 12 inches in diameter, rarely to as much as 2 feet. In the upper end of the deposit gold is confined to bedrock and the first 8 inches above it, but farther down the valley it is distributed through the lower 6 or 8 feet. Even here, however, the greater amount is next the bedrock. The gold is of the size of shot in the upper part of the basin but grades into flake gold below. Very rarely nuggets up to 75 cents in value have been found.

CARMEN CREEK DISTRICT.

GENERAL FEATURES.

The Carmen Creek mining district comprises an unorganized area around the headwaters of the creek whose name it bears. Salmon, about 15 miles southwest, is the nearest railroad and supply point. The history of the district is essentially the history of Oro Cache mine, this being the only property which has produced an important amount of bullion. The Oro Cache mine was opened about 1897. A 10-stamp mill erected shortly thereafter was operated intermittently for some years, the last run being made in 1907. In the spring of 1910 a small Ford quartz mill was installed at the Carmen Creek property, located in 1904, on the north branch of Carmen Creek, but only a small amount of bullion has been produced. The other claims in the district are in an early prospect stage.

GEOLOGY.

The Carmen Creek district is situated on the rugged western slope of the range forming the Beaverhead Mountains. Deep, narrow

canyons separated by rough, serrate ridges make the upper reaches of the area almost inaccessible, but its lower part merges into the Salmon River Valley and is in many places suitable for agriculture.

The district is well within the area of Algonkian schists and quartzites, which here strike N. 20°–55° W., and generally dip west at angles higher than 45°, although showing local variations to the east. Intricate jointing and advanced metamorphism characterize the rocks. Igneous material was not seen in the district, but a few miles north at the head of Boyle Creek outcrops of granite are reported.

ORE DEPOSITS.

Two types of deposits occur in the district—gold-quartz veins in quartzite and gold-copper replacement deposits along shear zones in schist. The Oro Cache deposit represents the former and the Carmen Creek mine the latter type.

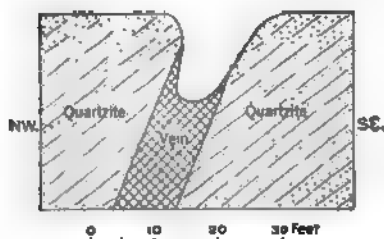


FIGURE 18.—Cross section of Oro Cache vein, Carmen Creek district, from exposure above lower tunnel, showing depression at outcrop.

ORO CACHE VEIN.

The Oro Cache vein occurs near the eastern margin of the district at an elevation of 8,200 feet. It is developed by nine tunnels distributed up the mountain side. The lowest and deepest tunnel is 700 feet long; the combined length of the others is about 2,800 feet.

The vein, which is inclosed in massive fine-grained argillaceous quartzite, strikes N. 65° E. and dips 67° NW. It is fairly constant in width, averaging about 4 feet, and has well-defined walls. (See fig. 18.) That the vein follows a fault is shown by a gouge seam about 8 inches wide which occurs along the hanging wall and includes many subangular fragments of quartzite, evidently shaped by faulting movements. In general but little primary ore has been encountered. A specimen secured from a protected pocket, however, consists of pyrite and a little chalcopyrite, galena, and sphalerite. In hand specimens the metallic minerals are irregularly scattered through pale-blue coarsely crystalline quartz, but in the vein they present a roughly banded arrangement parallel to the walls. The altered portions of the deposit are very abundantly stained by manganese. In some places lenticular openings are lined by small quartz crystals which stand perpendicular to their walls; again, similar openings are largely filled by pyrite. About 4,000 tons of ore, averaging \$8 a ton, are said to be blocked out in the mine.

CARMEN CREEK ORE DEPOSIT.

The Carmen Creek ore deposit, which crosses the north branch of Carmen Creek at an elevation of 6,900 feet, strikes N. 55° W. and dips 70° SW. In general outline the deposit is tabular, suggesting a vein, but owing to its internal make-up it may best be designated a replacement deposit along a shear zone in schist. The inclosing formation, which is of sedimentary origin and intensely metamorphosed to quartzite and mica schist, seems to correspond in strike and dip with the ore body. (See fig. 19.)

The ore occurs as lenses of quartz distributed through a band of schist 8 to 15 feet wide, in amounts sufficient to constitute about one-third of the total width. Much of the schist itself is mineralized. In addition to the metallic minerals, actinolite and magnetite are rather widely developed; green epidote is less common. Much of the vein quartz includes magnetite, but actinolite and epidote seem to be confined to the schist material adjacent to the quartz filling. The metallic minerals are largely contained in the quartz, and consist of pyrite and chalcoppyrite, the former generally altered to limonite and the latter to bornite and malachite, with a little chalcocite, and very little azurite. Free gold and some horn silver occur in cavities and along fracture planes in the secondary ore. Manganese stains are abundant.

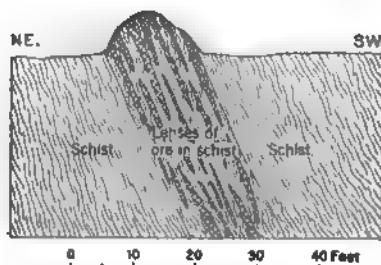


FIGURE 19.—Geologic relations and surface expression of Carmen Creek vein, Carmen Creek district.

AGE AND GENESIS.

From analogy with other deposits in the area it is believed that the veins are of late Cretaceous or early Eocene age. That they were formed at a great depth and under intense heat and pressure is shown by the development of magnetite, actinolite, and epidote in the Carmen Creek ores, minerals which when associated with each other indicate deposition under high temperature and pressure. Although igneous rock is not known closer than several miles, this deposit is strongly suggestive of its proximity, though probably not yet exposed by erosion.

GIBBONSVILLE DISTRICT.

SITUATION AND ACCESS.

The Gibbonsville district comprises the northern half of the territory drained by North Fork of Salmon River. It lies in the northward-pointing elbow of the Idaho-Montana line that is conspicuous

on maps of the State. The district is readily reached by wagon road from Salmon, 30 miles south, and less easily from Pioneer, Mont., about 20 miles east. A trail crosses the mountains into the Bitterroot Valley to the northwest.

The town of Gibbonsville is a small settlement with store and post office; reached triweekly by stage from Salmon. It is the only town in the district. (See Pl. XVII.)

HISTORY AND PRODUCTION.

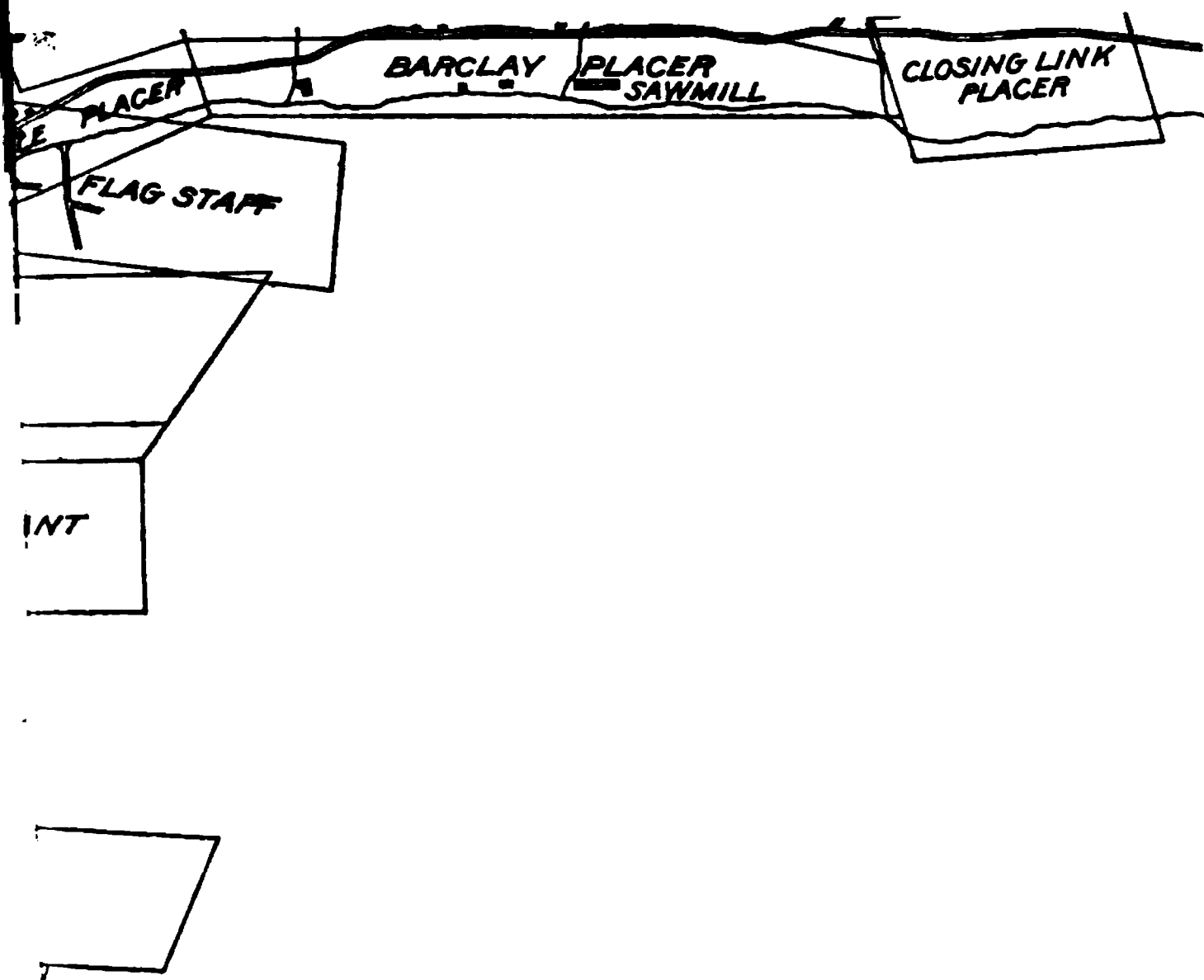
Placers were discovered on Anderson Creek in 1877, and although not very productive their presence led to the location of gold-bearing veins in September of that year. During the fall one arrastre was built, and the next year two were added. By this means of treatment \$20 to \$30 per ton was saved. Early in 1881 most of the producing mines were sold to an English company, which later went into liquidation and sold the properties to Adelbert Ames, of New York, who operated them for a number of years. After changing hands several times the American Development, Mining & Reduction Co. purchased the principal group and in 1895 erected a 30-stamp mill with accessory cyanide and chlorination plants. This company operated until March 20, 1898, when it also became insolvent, the receiver and others operating the property intermittently until July, 1900, when the American Development, Mining & Reduction Co. resumed control.

The district received a decided setback in the fall of 1907 from the destruction by fire of the principal reduction plant. Since then two or three small stamp mills, which during the activity of the large plant were mostly idle, have treated the ores of the camp.

As is commonly the case where gold ore is treated locally by a number of companies operating through a period of years, the production is not accurately known. Much of the ore milled has contained from \$20 to \$50 in gold per ton, but of this possibly less than 70 per cent has been recovered. From the large tonnage, however, it is believed that the current estimate of \$2,000,000 for the production of the district is not unreasonable.

TOPOGRAPHY.

The Gibbonsville district occupies a broad mountainous amphitheater-like basin, circled on the north, east, and west by the mountain range which forms the Idaho-Montana boundary. The basin opens to the south and is drained and deeply carved by the several streams which unite to form North Fork of Salmon River. Although slopes are rather less precipitous than in the more mountainous parts of Lemhi County, abrupt changes in elevation between 4,500 and 7,000 feet are common. The mountain slopes are clad with a dense



growth of grasses and small shrubs, above which rises a forest of medium-sized evergreen trees. This growth conserves the winter's supply of moisture, so that the streams live throughout the year, affording abundant water for milling and power purposes.

GEOLOGY.

The predominant rock formation is made up of a great succession of quartzites, quartzitic slates, and micaceous slates which strike about 20° W. and most of which dip 40° to 70° E. Micaceous slates constitute perhaps three-fourths of the series; next in importance are quartzitic slates; and very subordinate in amount are quartzites. The series is thin bedded throughout, and the different kinds of rock follow each other in monotonous succession.

A belt of igneous rock, about 100 feet wide and probably to be classed as a basic diorite, extends north and south through Gibbonsville. It corresponds in strike and apparently agrees in dip with the bedding of the sedimentary rocks. Small dikes of a similar rock noted in the American Development, Mining & Reduction Co.'s mine, together with the coarse texture of the larger body, suggest that the latter is of intrusive origin, and the extensive development of schistosity in it may indicate that it has passed through the period of metamorphism which altered the Algonkian sediments. Thus it is thought that the dioritic intrusion, occurring both as a sill and as dikes, is very old, possibly pre-Cambrian. More recent igneous activity is represented by the andesite, which occupies many of the hilltops and higher slopes west of Gibbonsville.

Faulting is extensive in the area and has proved a serious handicap to the profitable exploitation of the deposit. Many faults are of the type commonly designated reverse, but enough are of the normal type to make a general rule for the miner of little value. Most of the displacements thus far encountered have offset the vein less than 50 feet. (See fig. 20.)

ORE DEPOSITS.

The ore deposits at Gibbonsville occur in narrow east-west veins. Eight or ten have yielded a total of \$2,000,000 in gold, and fifteen or twenty more have afforded reasonable encouragement to the prospector. Some of the veins dip north and others south, both at high angles, usually more than 70° . Most of them are narrow fissures, averaging less than a foot in width, though some are 5 or 6 feet wide, as on the Twin Brothers property. The gangue is coarse clear-white quartz, in places heavily impregnated by pyrite, which occurs as scattered cubes, fine-grained masses, irregular blotches with quartz intermixed, and patches of coarse crystal aggregates. In general the pyrite has a crude zonal arrangement parallel to the vein walls,

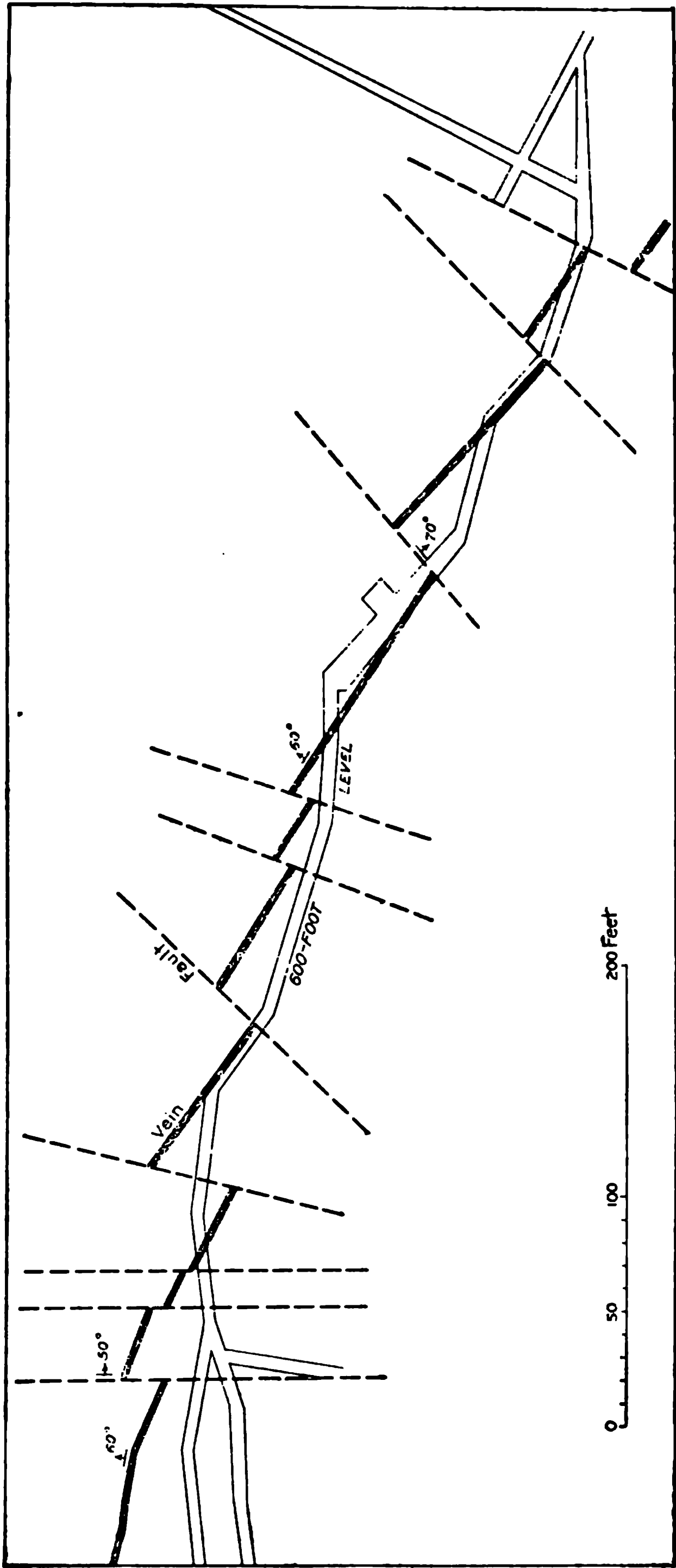


FIGURE 20.—Section of Sucker vein at 600-foot level, American Development, Mining & Reduction Co.'s mine, Gibbonsville district. Shows offsets in vein by faulting. Faults commonly agree in strike and dip with formations. Compiled from maps in the office of the company, with additions.

although it varies markedly from place to place, both in arrangement and in amount. There are all gradations, from ledge matter predominantly pyrite to that exclusively quartz. Here and there calcite appears in the gangue and in places chalcopyrite is found, in places in amounts sufficient to appreciably interfere with normal cyanide treatment. In the primary ores the gold, which in different properties averages from \$10 to \$40 per ton, varies directly with the pyrite, and as only 40 per cent of the gold yields to amalgamation it is probably included in the pyrite.

The limit of predominant oxidation in the district has in few places been found to exceed 150 feet and in many is less. If ground-water level be defined as the horizon at which water stands in a shaft throughout the year, it is probable that the deposits are oxidized considerably below the average ground-water level in this district. This, however, is a normal relation, for the ore deposits are situated on the sides of the mountains, high above the valleys which determine low points in the water table. Other factors being equal, oxygen-bearing underground water will circulate from the divides to the valleys. It is obvious that if such circulation is sufficiently slow a shaft reaching a point not nearly as low as the bottom of the valleys may contain water throughout the year.

The ore occurs in shoots which pitch eastward with the dip of the inclosing formation. Their distribution seems to bear a definite relation to the kind of inclosing rock; a given vein crossing the several types of rock is commonly barren in the diorite, poor in the quartzite, and productive in the black clay slate. Within the shoots there is a secondary concentration whereby a leached zone of 15 to 30 feet is found at the surface, followed by a zone of enriched ore extending usually to about 100 feet, at which depth it grades into the unaltered deposit. (See p. 80.)

MINES.

AMERICAN DEVELOPMENT, MINING & REDUCTION CO.'S MINE.

The A. D. & M. mine, as the American Development, Mining & Reduction Co.'s mine is commonly designated in the district, is situated on the south face near the base of the mountain northeast of Gibbonsville. It is estimated that from 25,000 to 30,000 feet of development work has been done on the property, most of it on the 600-foot or No. 3 tunnel level from which the Rattler, Sucker, Sucker Extension, Diana, Keystone, Lone Pine fraction, William Edwards, and Waterloo grounds are reached. From this level raises lead to the surface and a double compartment shaft reaches the 800-foot level. From the 700-foot level an incline extends to the 900-foot or deepest level. Nearly all the stoping has been done above 800 feet.

The total production of the property is estimated at a little more than \$1,000,000.

The country rock is quartzite, quartzitic slate, and micaceous slate, all thinly laminated and striking N. 10°–20° W., with dips of 40°–70° E. Although regional metamorphism has caused much recrystallization in the slates, slaty cleavage is not developed and in most places the bedding structure is apparent. The quartzites are fine grained and firmly cemented. In places both the quartzite and mica slates grade into a compact black slate almost devoid of biotite. It is when inclosed in this rock that most of the veins have presented their highest degree of metallization.

In the western part of the workings a basic diorite, possibly of pre-Cambrian age, has been encountered. It conforms in strike and dip with the sedimentary rocks and is cut by the veins.

Many faults occur in the mine. They strike north and south and dip east with the bedding in most places, but in others at higher angles. Figure 20 illustrates ten such faults and shows their influence on one of the veins.

Six or seven veins have been encountered in the mine, all of them striking east and west, and all except the Eckhart dipping 50°–85° N. These veins are thin tabular bodies and present a marked variation in thickness from place to place, both along the strike and dip. The larger ones average perhaps 12 inches in width. The better ores occur in shoots, which pitch east at about the angle of the inclosing rock. As a rule the ores are higher grade where the inclosing rock is black slate, and comparatively lean where it is quartzite or diorite.

The outcrops of the veins usually have little or no topographic expression. Heavy iron and some manganese stains are everywhere present in them, and in places a short distance below the surface the vein material is an earthy mass of manganimiferous hematite. The upper 10 to 50 feet is much poorer than the next 100 feet or so, and at 150 to 200 feet primary ore is reached.

The primary ore consists of pyrite, with a few crystals of chalcopyrite, in a silica gangue rarely including a little calcite. The pyrite appears as cubes, as fine-grained disseminations, and as patches. In its broader distribution the ore occurs in shoots which vary in length from 25 to 300 feet, and within the shoots pyrite has a rather even general distribution, although in detail such as is seen in the hand specimen a bunchy arrangement is pronounced.

The primary ore carries about \$30 in gold, some 40 per cent of which may be recovered by amalgamation. It is possible, however, to increase the percentage of recovery to 60 or even to 85 per cent (according to the amount of copper present) by treating the concentrates with cyanide.

CLARA MORRIS GROUP.

The Clara Morris group, comprising 14 patented claims, is situated on the western slope of the mountain immediately northeast of Gibbonsville. This property is one of the older ones in the district. It has been located and relocated several times, finally being formed into a group and patented in 1900. Operation, which resulted in some 2,500 feet of development and a production of about \$250,000, was carried on at intervals from 1888 to 1908. As with the other properties in camp, reduction was first by means of the arrastre and in later years by stamp mill and cyanide.

The following notes on the geology and ores are derived entirely from examination of surface exposures and from conversation with Mr. George Hughes, of Gibbonsville, for many years connected with the property, the tunnels now being inaccessible.

A broad belt of diorite extends along the western margin of the group. It is apparently parallel to the bedding of the formations, which strike N. 20° W. and dip about 60° NE. East of this belt the formation is a monotonous succession of quartzites, quartzitic slates, and mica slates. Extensive postmineral faulting is said to be shown by the multiplicity of offsets encountered in following the veins, the greatest displacement being 42 feet.

About twenty-seven veins, all extending east and west and most of them dipping south, are reported in the group. Many of these are worthless or of doubtful merit, and but two, the Clara Morris and the Nevada, have proved valuable. In these two the ore occurs in shoots up to 300 feet in length, averaging about a foot in width. The vein filling is almost exclusively pyritiferous quartz, the pyrite varying in amount markedly from place to place, and with it the gold. The ore netted about \$25 a ton. Where traced into the diorite the veins have usually been barren.

TWIN BROTHERS GROUP.

The Twin Brothers group occupies the north and west slopes of the mountain immediately southeast of Gibbonsville. The property is said to be developed by some 5,000 feet of tunnels and raises which have afforded a total of 35,000 or 40,000 tons of ore from four or five veins. As in the properties already described, the deposits are pyritic quartz veins filling east-west fissures in metamorphosed slates and sandstones. The ore is somewhat lower in grade than in the properties north of Dahlenega Creek, running \$11 or \$12 a ton, but the ore bodies are much wider, some of them 5 or 6 feet.

The ores are treated in a 10-stamp mill by simple amalgamation, the recovery being about \$9 a ton. The total production is estimated at \$300,000.

OTHER PROPERTIES.

The Roland and Taylor group consists of four claims situated in Anderson Creek valley a mile north of Gibbonsville. A wide, nearly vertical quartz lode striking north and south extends through the property. It is highly altered, heavy stains of iron and manganese being generally present. Locally cores of unaltered ore show pyrite and some chalcopyrite to be the principal metallic minerals. The ledge is held for gold, \$3.50 a ton being claimed.

The Bull of the Woods property is situated on Hughes Creek, about 4 miles west of Gibbonsville. The veins are included in eastward-dipping quartzites and slates, the former being more abundant than near Gibbonsville. The extent and value of the ore bodies has not been adequately determined, and save through a few small placers the deposits have produced little or no bullion. A large stamp mill has recently been erected on the property, but at the date of the visit the machinery was only partly installed.

The Chief and Eckhart claims, together with several others, have had a small production. Most of them are individual claims adjacent to larger properties through which they are worked.

INDIAN CREEK DISTRICT.**SITUATION AND HISTORY.**

The Indian Creek mining district is situated along Indian Creek, which enters Salmon River about 30 miles below Salmon. Ulysses, a small settlement dependent for its existence upon the mines, is the only town in the district. It is reached triweekly by stage from Salmon. (See Pl. XXI, *B*, p. 152.)

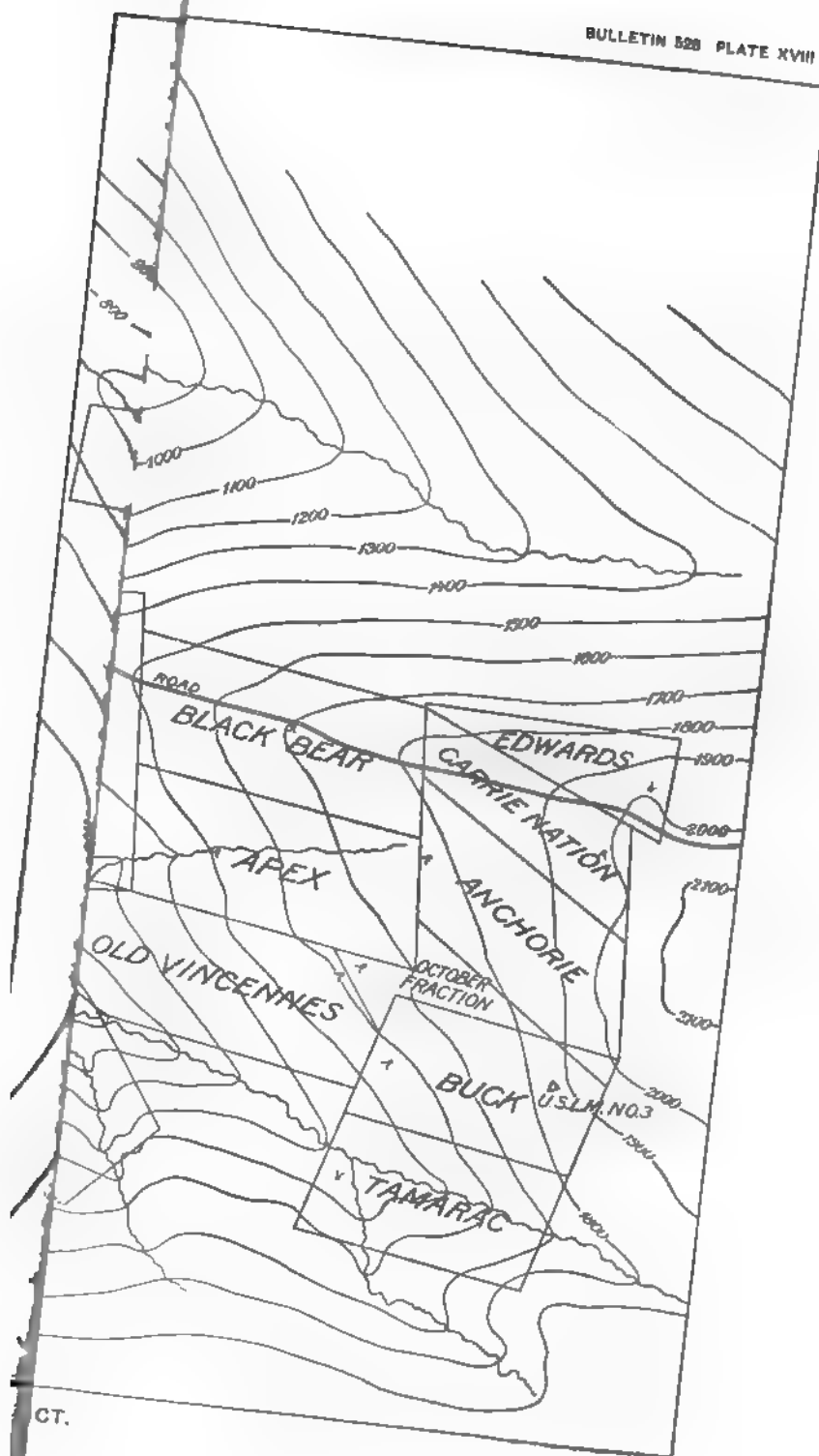
Claims were first located in the district in 1895, but little work was done until the Kittie Burton Gold Mining Co. acquired the two leading properties, the Kittie Burton and Ulysses, in December, 1901. (See Pl. XVIII.) With the rapid development and successful operation of these mines other properties were located in the district, but none of them has been profitably operated. The Kittie Burton Co. has, however, continued operations on its properties, save for two or three short intermissions, since its organization.

TREATMENT OF ORES AND PRODUCTION.

Three or four small amalgamation mills have been operated from time to time in the district, but the only one which has turned out bullion in recent years is the mill of the Kittie Burton Gold Mining Co., which is equipped with three 5-stamp batteries, each followed by three amalgamation plates and a Wilfley table. About 80 per cent of the gold is recovered directly, part of the remainder being secured from concentrates by smelting. Two grades of concentrates are run;

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BULLETIN 528 PLATE XVIII



the lower, averaging about \$22 a ton, is stored; the higher, averaging about \$70 a ton, is sacked and shipped to the smelter.

The average cost for mining and milling 68,194 tons of ore from January, 1903, to July, 1907, was as follows:

Cost per ton for mining and milling Kittie Burton gold ores.

Mining.....	\$2.56
Milling.....	1.14
Transportation from mine to mill.....	.25
	<hr/>
	3.95

The total production of the district is a little less than \$600,000, of which the Ulysses mine has produced three-fourths and the Kittie Burton most of the remainder.

PHYSIOGRAPHY.

The Indian Creek mining district includes the central part of a small drainage basin 35 miles northwest of Salmon. Tributary to the great canyon of Salmon River, this basin corresponds to it in depth of valleys and steepness of slopes, especially in its southern part. Extremes in elevation range from 3,500 feet to more than 7,000 feet, and transitions of more than 2,000 feet within short distances are common. Indian Creek, a small stream heading against the Continental Divide, flows south through the district, affording abundant water for power and milling purposes save in winter when freezing temperatures make it impossible to keep flumes open.

GEOLOGY.

The predominant rocks of the region are the metamorphic equivalents of Algonkian shales, sandstones, and intermediate forms, perhaps 75 per cent of the total being quartzitic biotite slate. The series is rather intensely and very uniformly metamorphosed; little crumpling is noted, and where the primary structure is minutely distorted it is by gentle flexures rather than by crimping bends.

The igneous rocks of the area are Archean gneiss older than the Algonkian sedimentary rocks, pre-Cambrian (?) diorite associated with the sediments, late Cretaceous granite and associated aplitic dikes, and granite porphyries younger than any of the others.

The several types of rock may be seen along the road between the mouth of Indian Creek and Ulysses. A broad belt of gneiss crosses the canyon about 2 miles below the mines. It is readily recognized by its large feldspars, many of them an inch or more in length, which are somewhat drawn out and appear as thick lenses around which curve sheeted bands of fine-grained biotite and quartz. The diorite appears in float along Indian Creek; it is a fine to medium grained greenish-black rock, darker and coarser than any of the dike rocks

with which it might be confused. The granite, distinctive as a dark-gray medium to coarse grained equigranular rock commonly having much brilliant black biotite uniformly scattered through it, is widely exposed near the mouth of Indian Creek. Aplite dikes appear at many places on the valley sides near Ulysses; they are fine-grained rocks of light-gray or pale olive-green color, containing scattered quartz grains and, generally, cubes of pyrite as the only recognizable crystals. Rhyolite porphyry dikes are not numerous, the only one noted appearing about $1\frac{1}{2}$ miles below Ulysses on the west side of the valley at an elevation of 4,150 feet; the rock is dark gray in color and is made up of crystals of quartz, orthoclase, and hornblende, rather sparsely set in a fine-grained groundmass. In general it shows more crystals and is fresher than the other dike rocks.

Microscopic descriptions of these several rocks appear in the general section on igneous rocks.

The structural relations of the district are by no means simple. The strike and dip of the sediments change repeatedly and abruptly within short distances, although the variations fall between a strike of northeast and southwest with dip southwest and east and west with dip south.

Strong joints are conspicuous throughout the area, the granite, however, being much less jointed than the old sediments and gneiss. In the granite the joints in general seem to extend N. 20° W. and at right angles thereto; in the metamorphic rocks they extend, in addition, N. 10° E. and at right angles thereto. It thus seems that the joints are assignable to two ages, pregranite and postgranite, those of earlier age being much more numerous. Slips and faults are largely along lines of jointing. Thus in the Ulysses mine some faults offsetting the ore strike N. 10° – 30° W. and dip southwest, and others strike N. 60° – 70° E. and dip northwest. Though faults are numerous, none with a vertical displacement of more than 100 feet has been recognized.

ORE DEPOSITS.

ULYSSES VEIN.

The Ulysses mine is situated on the steep valley side east of Ulysses, 1,400 feet above the town. It is reached by wagon road and connected with the mill at Ulysses by aerial tram. The vein, a tabular body varying in width up to 10 or 12 feet, strikes east and west and dips 10° – 25° S. Its general flat dip, corresponding roughly with the slope of the hill, has made it feasible to work considerable areas near the outcrop by stripping the overlying material. (See Pl. XIX.) Nowhere has the vein been found to extend to a depth of more than 150 feet.

Slates and quartzites inclose the vein, which in most places corresponds in strike and dip. A fine-grained granite porphyry, very



ULYSSES MINE, INDIAN CREEK DISTRICT.
Showing distribution of tunnels and open cuts along the flat-lying Ulysses vein.



probably younger than the ore, overlies the vein in some places and in others underlies it. The vein filling is coarsely crystallized quartz but includes also much silicified wall rock. In places a little calcite accompanies the quartz. Pyrite, most of it in cubes but some of it in irregular patches, is conspicuous locally, and chalcopyrite and braunite appear in places. In general, however, the minerals are the common oxidation products of those just mentioned. Gold is distributed quite generally through the deposit in amounts equivalent to \$1.50 or more per ton, but those parts sufficiently rich to justify handling are confined to large bodies erratically distributed in the vein. These average \$7 or \$8 per ton. It is noteworthy that

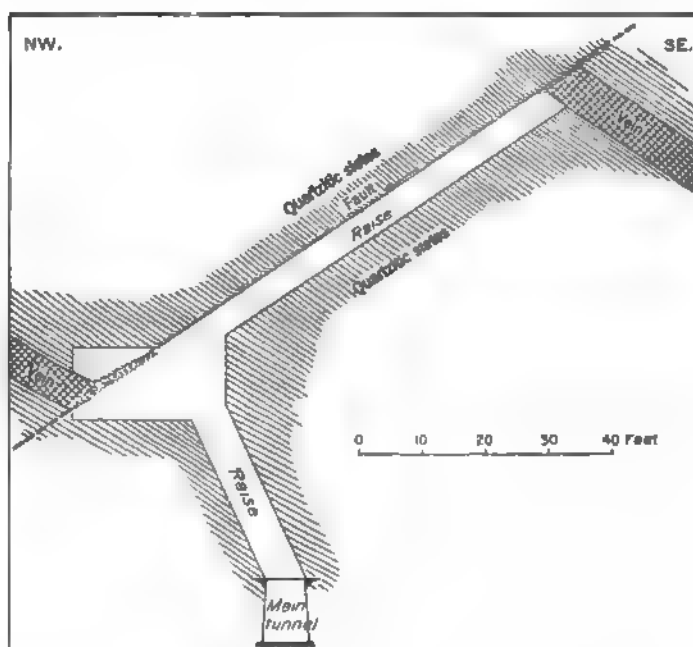


FIGURE 21.—Section at point 250 feet from portal of main tunnel, Ulysses mine, Indian Creek district. Shows normal faulting of vein.

secondary enrichment has not been encountered in the oxidized ores, for iron and manganese are abundant, a combination which makes possible the solution of gold under surface conditions.

The vein is offset by several step faults (fig. 21) which successively increase its elevation northward.

KITTIE BURTON VEIN.

The Kittie Burton mine is situated on the canyon side west of Ulysses at an elevation 1,200 feet higher than the town. It is reached from Ulysses by wagon road and connected with the mill by aerial tram. The vein, inclosed in slates and quartzites, strikes N. 20°-30°

W. and dips 40° SW. in the upper 100 feet but is almost flat below that depth. In its more highly dipping section its average width is 3 to 4 feet, but in its flat part, known as the "big stope," it attains a maximum thickness of about 30 feet. From a level below the "big stope" and west of it, a winze has been sunk 40 feet on a vein which lies parallel to and west of the vein above the "big stope." Whether or not these are portions of the same vein has not yet been shown by development.

The vein filling, a coarsely crystallized bluish-white quartz inclosing much silicified wall rock, is in every way similar to that found in the Ulysses mine. In addition to abundant pyrite and some braunite and chalcopyrite, pyrrhotite is present in the ore. Of the minerals produced by oxidation, iron and manganese oxides are abundant, rhodochrosite appears as minute crystals on fracture surfaces, and malachite and azurite and rarely native copper are found in small quantities near the surface. Oxidation extends throughout that part of the deposit which has been explored, although as a whole the ore is rapidly becoming baser.

OTHER VEINS.

Veins have been found near the head of Sage Creek and at various places on the mountain slopes southeast and southwest of Ulysses, but as they are not commercially important so far as known, and as they do not differ in type from the Ulysses and Kittie Burton veins, they are not described.

MINERAL HILL DISTRICT.

SITUATION AND ACCESS.

The Mineral Hill mining district comprises a large area lying about 45 miles northwest of Salmon. On the north, east, and south it merges into the Mineral Point, Indian Creek, and Mackinaw districts, respectively. On the west no boundaries, even approximate, are recognized. Shoup, a small settlement on the north bank of Salmon River centrally located in the district, has triweekly mail communication with Salmon. A stage road down Salmon River reaches a point within 6 miles of Shoup, where it gives way to a narrow trail which winds along the canyon's side. Supplies are floated down the river on barges as far as Shoup, below which treacherous rapids make water transportation extremely hazardous.

Only the southern part of the district was visited during 1910, the northern part having been previously visited and briefly described by Lindgren.¹

¹ Lindgren, Waldemar, A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: Prof. Paper U. S. Geol. Survey No. 27, 1904, p. 90.

HISTORY AND PRODUCTION.

The district was discovered in 1882, the Grunter and Kentuck properties being located in that year. These locations were followed by the Big Lead in 1886, the Clipper Bullion in 1887, and the Monolith in 1889. During the first two years the ore was treated by arrastres and a single stamp. In 1884 the Kentuck Co. erected a 10-stamp mill, and during the succeeding few years four other mills were erected on as many properties, so that now 55 stamps are in place. Treatment of the ores in these mills has not, however, been wholly satisfactory, owing to the crude construction of most of them and to the fact that the ores rapidly became base with depth.

The total production of that part of Mineral Hill district adjacent to Shoup has probably been a little more than \$750,000; about two-thirds of this amount has come from the Kentuck mine, the Grunter and Monolith affording most of the balance, although two other properties—the Clipper Bullion and Big Lead—have supplied some bullion.

TOPOGRAPHY.

Mineral Hill district is a forest-clad area of exceptional boldness of relief. Trenched across its southern part by the canyon of Salmon River, a narrow gorge 2,000 to 4,000 feet deep, which determines the depth of numerous tributary canyons, the area shows a succession of deep gashes, the sides of which rise abruptly until near the level of the uplands, where they grade back into broadly rounded topographic forms. The properties described later occupy the lower and middle slopes of the canyons of Salmon River, of Boulder Creek, a small tributary from the north, and of Pine Creek, which enters from the south.

GEOLOGY.

The uplands are in many places capped by sedimentary rocks of Algonkian age, now extensively metamorphosed to mica schists, slates, and quartzites. The base of these, separated from the underlying gneiss by an erosional contact, is a fine-grained biotite schist, locally containing much arkosic material derived from the gneiss. Above this schist is an oft-repeated succession of slates and quartzites. The series, although varying markedly in attitude from place to place, in general strikes N. 20° W. and dips 45° NE.

Granite gneiss, the oldest rock in the county, forms the canyon walls near Shoup and extends as a broad area north and west. Within its general field many caps of Algonkian rocks are yet preserved, but owing to lack of detailed knowledge concerning them, they are not shown on the map (Pl. I, in pocket). The gneiss is readily recognized in the field by its large feldspar crystals, many of

which are crushed and drawn out into lenslike masses. Curving about these are foils of biotite and crude bands of granulated quartz, which by their arrangement give the rock a decidedly banded appearance.

Both the gneiss and the Algonkian sedimentary rocks are intruded by a great granite batholith, which is beautifully exposed in the canyon a few miles above Shoup and on the slopes to the southeast. The rock is dark gray, medium to coarse grained, and commonly equigranular. Although biotite is generally abundant, giving a mottled appearance, it is locally almost absent. This granite is distinguished from the granite gneiss by smaller feldspars, general lack of schistosity, and freshness of appearance.

Within the district dikes of coarse and fine grained granite porphyry, diorite, basalt, and quartz diorite porphyry were noted. The granite porphyry dikes are most numerous, at least six being seen, and are said to have the greatest extent. They are from 50 to 100 feet wide and extend in a general course N. 10°-20° E. The rock has a medium to coarse porphyritic texture with quartz and feldspar crystals set in a fine-grained bluish-gray groundmass. Next in importance, and younger than the granite porphyry, are the quartz diorite porphyry dikes, which in general strike N. 70° E. This rock is characterized by a dark-gray fine-grained groundmass, sparsely studded with medium-sized feldspar and fewer quartz crystals. Biotite and hornblende appear as small, brilliant, black phenocrysts. Possibly still younger, and with strike parallel to that of the quartz diorite porphyry, is a fine-grained equigranular grayish-black rock consisting of plagioclase, hornblende, and biotite. This rock is classed as diorite. Another type of dike, greatly altered but evidently a basalt, was noted in the Monolith mine. A similar rock, but fresh, accompanies the vein in the Clipper Bullion mine. The age of the basalt with reference to the quartz diorite porphyry is not known, but it is clearly younger than the veins.

ORE DEPOSITS.

The deposits of the district, all of which are mined for gold, are grouped around Shoup, in the southern part of the district (Pl. XX), and around Mineral Hill, in the northern part. Only the former were visited. Six or eight veins have been prospected. All the more important strike northeast and southwest and dip southeast. This general attitude is entirely independent of the schistosity of the gneiss and the bedding of the slates and quartzites but corresponds to the extensive joints which may be recognized in most exposures in the area. Faulting, although common, has been found to displace the ore seriously in only a few places.

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KENTUCKY MAIL

The Kentuck, the chief mine of the Mineral Hill district, is situated 1 mile west of Shoup at an elevation of 1,200 feet above Salmon River. The property was located in 1882, and immediately thereafter pro-

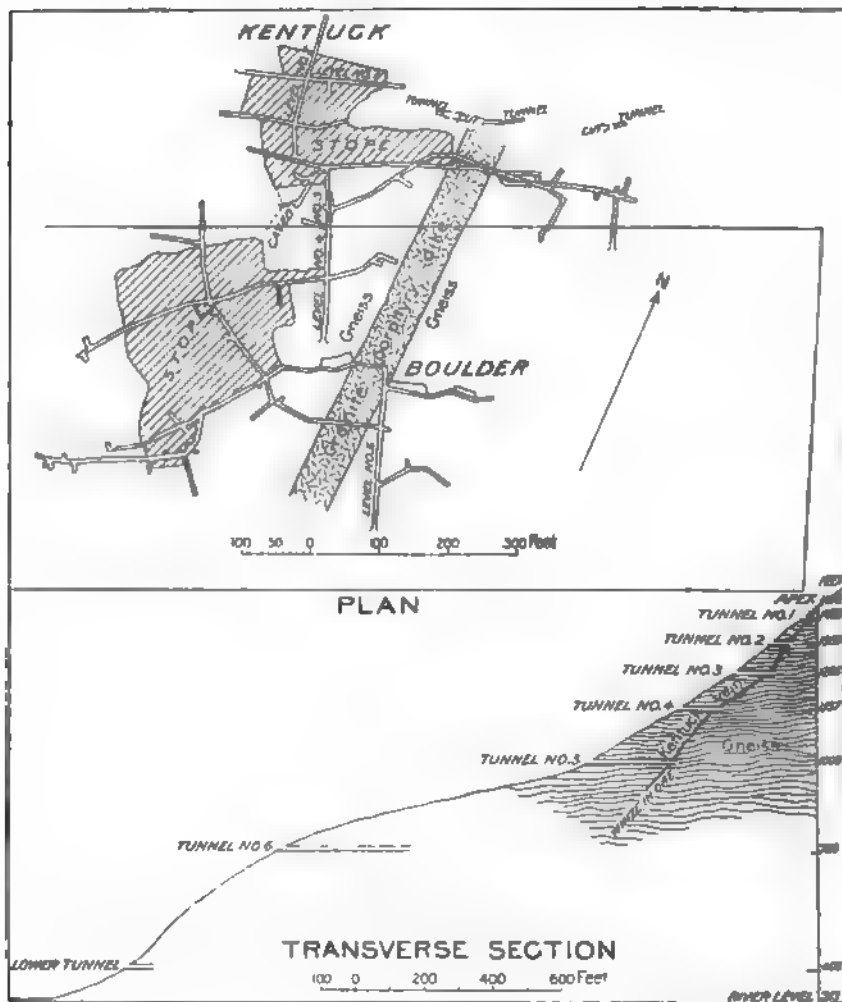


FIGURE 22.—Plan and transverse section of Kentucky mine, Mineral Hill district. Adapted from maps in the company's office, with geology added.

duction began. During the first two years the ore was worked by a mill with a single stamp and two arrastre beds. In 1884 a 10-stamp mill was erected, and from that time until 1890 the mine experienced its greatest period of production, which gradually waned during the next three years to its present inactive state. The property has

yielded about 45,000 tons of ore which, on a basis of 40 per cent recovery, is said to have netted a fraction less than \$10 a ton.

Development work on five levels opens a total depth on the vein of about 700 feet, although, owing to the approximate coincidence in dip of the lode and slope of the hill, a vertical depth greater than 200 feet has not been obtained. Most of the development and stoping has been done from the fifth level. (See fig. 22.)

The vein, which strikes N. 70° E. and dips 40° SE., is from 2 to 6 and in a few places 8 feet wide. It is inclosed in gneiss, which is cut by granite porphyry dikes younger than the vein and by quartz diorite porphyry still more recent. The ore is coarse-grained bluish-white quartz with pyrite, and in places has arsenopyrite, galena, and a very little sphalerite scattered irregularly through it. In the upper workings little ore was found to be oxidized for more than a few feet below the surface.

MONOLITH MINE.

The Monolith group lies a mile north of Shoup on the east side of Boulder Creek at an elevation of 4,100 feet. Development consists of several open cuts and small tunnels in addition to a principal tunnel which extends in 600 feet on the strike of the vein and from which raises and stopes connect with the surface 150 feet up the dip. The production of the property is said to be about \$175,000 from ore which plated somewhat less than \$10 a ton.

The country rock comprises both metamorphosed sediments and gneiss. In the workings quartzites and slates predominate, although gneiss crops out a few hundred feet below the tunnel. Both types of rock are extensively jointed. Granite porphyry, quartz diorite porphyry, and basalt occur as dikes.

The deposit, a tabular body from a few inches to 4 feet in width, strikes N. 12° E. and dips 10°–30° SE. Within the coarse quartz gangue, pyrite, nowhere abundant, appears as intergrowths and as films along joint cracks; galena occurs in small amounts, both as cubes and fine-grained bunches; sphalerite is rare, as is also arsenopyrite. Oxidation is not extensive, primary minerals commonly appearing within a few feet of the surface. Near the hanging wall, however, a narrow oxidized zone apparently serves as a water channel through the deposit which, as now exposed, is far above ground-water level.

GRUNTER MINE.

The Grunter mine is situated half a mile below Shoup and a few hundred feet north of Salmon River. The property was the first located in the district, and in the few years following its discovery, in 1882 produced some \$50,000 from ores procured near the surface. The vein has never been explored in depth, most of the workings being open

cuts, in places connected by short tunnels. The country rock is gneiss locally impregnated with pyrite, and rather generally silicified near the vein. The ore body is an irregular deposit, which in some places strikes N. 70°–80° E. and dips 30°–70° SE. and in others strikes N. 10° W., with dip variable but averaging perhaps 70° E. The quartz varies from 2 to 40 feet or more in width, the wider parts being generally angular in general outline. Mineralogically the deposit is rather simple, pyrite and sparse galena, sphalerite, and arsenopyrite being the only minerals noted. Oxidation has taken place only along the stronger joint cracks and within a few feet of the surface.

CLIPPER BULLION MINE.

The Clipper Bullion property consists of 10 claims south of Salmon River, half a mile from Shoup. Since its location in 1887 some 2,500 feet of development work has yielded about \$75,000 in gold.

Three veins, all of which are inclosed in gneiss, have been opened on the property. They appear at successively higher elevations on

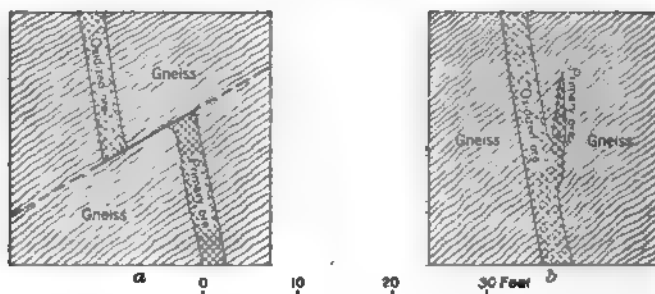


FIGURE 23.—Sketch illustrating oxidation in Tramway vein, Mineral Hill district. *a*, Influence of cross fault on oxidation of ore body; *b*, an upward spur which has not been attacked by oxidizing agents, though well within the zone of oxidation.

the mountain side and are locally known as Tramway, Hennessey, and Clipper Bullion. The Tramway vein, which averages about 3 feet in width, strikes N. 70° E. and dips 80° SE. In the upper part it is a decomposed honeycomb quartz carrying free gold. It is faulted at short intervals but is never offset more than a few feet. One normal throw of particular interest parallels the vein in strike but has opposite dip; above it the ore was completely oxidized and below it unaltered vein matter was encountered. The ore consists of pyrite and a little galena, irregularly and rather sparsely scattered in a quartz-barite gangue. Within the oxidized zone the primary minerals have altered to iron oxide and cerussite (fig. 23), and native sulphur is very generally present in the cavities formed by leaching. In treatment the sulphur forms a scum in which much of the fine gold is lost.

The Hennessey vein, which averages about 20 inches in width, strikes N. 20° E. and dips 85° SE. It is composed of clear, coarse

quartz, in which are scattered pyrite crystals accompanied by free gold.

The most productive vein on the group is the Clipper Bullion, which averages about 3 feet in width, strikes N. 42° E., and dips 65°–85° SE. Only the oxidized zone, consisting of decomposed pyritic quartz, has been worked. Here, as elsewhere in the group, the ore occurs in small shoots, some of which are very rich. One shoot produced 1,000 tons of ore averaging \$43 per ton.

BIG LEAD MINE.

The Big Lead mine is a gold property situated on the east side of Pine Creek, about a mile above its junction with Salmon River. Development consists of about 1,500 feet of tunnels and a few small shafts. The production of the property is not known, but probably it has been small.

The rock formations include gneiss and slates intruded by granite and granite porphyry dikes. Several veins are recognized but only the most important was visited. This vein strikes N. 65° E. and dips 80° SE. It is inclosed in granite and ranges from a few inches to 3½ feet in width. Throughout the present workings the ore is extensively oxidized and iron stained, although crystals of pyrite and considerable magnetite appear in places. The gold is free. In many places the granite next the vein is a little altered, and numerous masses of schist included in the quartz, evidently having fallen into an open fissure from higher horizons, are intensely silicified.

The ore bodies on this group are large and fairly persistent but mineralization is not intense; \$6 to \$8 a ton is claimed.

MACKINAW DISTRICT.

SITUATION AND ACCESS.

The Mackinaw district includes an unorganized area of about six townships situated in the north-central part of Lemhi County. Broadly defined, it is bounded on the east by the mountain crest west of Salmon, on the north by Salmon River, and on the south and west by Big Creek. On the northwest the Mineral Hill district extends a short distance into this area, and in the northeast the Eureka district is frequently considered to include the Moose Creek placers. In this report, however, these are included in the Mackinaw district.

Leesburg, a settlement of 25 inhabitants, the local supply point and post office for the district, is reached triweekly by stage from Salmon, which in a direct line is about 9 miles east-southeast but by road is much farther. Lines of travel within the area include a stage road from Leesburg, east to Salmon and south to Forney. Secondary roads extend to Moose Creek with a branch to Beaver

Creek, and branches from the Forney road up Arnett and Phelan Creeks. Trails lead from these few roads into many parts of the district.

HISTORY AND PRODUCTION.

The location of placers on Napias Creek in July, 1866, makes the Mackinaw district by several years the oldest in Lemhi County. In spite of the fact that it was necessary to freight supplies from Fort Benton, in central Montana, and later from Corinne, Utah, a prosperous camp with more than 7,000 persons early sprang up at Leesburg. The first four years after discovery marked its period of greatest activity, although placer mining has continued down to the present time.

The first quartz mine, known as the Shoo Fly, was located in 1870 on the mountain east of Moose Creek basin. The ore body was not large and was soon exhausted. In 1880 the Gold Flint was located, and in 1892 the Italian mine. Withal, quartz mining has not proved nearly as productive as placer working. Some promising veins have been found, but most of the ore bodies have proved irregular in shape and low in grade.

As is true in most districts where rich placers are worked by many individuals and where gold dust is used in commercial trade and gambling is rife, it is impossible to form even an approximately correct estimate of the total amount of gold produced. It is also true that the estimates handed down by tradition in such districts are nearly always far too high. In the Mackinaw district long-time residents place the production at figures ranging from \$5,000,000 to \$30,000,000, but from the area of ground worked and its reported richness it seems to the writer that the former figure must be very much more nearly correct, possibly even high. In addition to this the lode mines have afforded bullion to the amount of about \$250,000, two-thirds of which came from the Italian mine and most of the remainder from the Shoo Fly.

PHYSIOGRAPHY.

The Mackinaw district is a high forest-clad area, deeply trenched in its marginal parts by canyons which extend into it from three sides. On the north the uplands join abruptly the precipitous sides of Salmon Canyon, and on the south and west meet the almost equally steep slopes of the trench occupied by Big Creek. Eastward the surface grades into the crest line, beyond which lies the broad valley in which the city of Salmon is situated.

The valleys in the central part of the area are broad and open, assuming their trenchlike character only as they approach the major streams on the margin of the district. Also characteristic of the uplands are the many features typical of glaciation. These are dis-

tinct on Napias and Moose creeks and about the head of Beaver Creek. Indeed most of the area above 8,000 feet and some of the valleys (Napias Creek) as low as 6,500 feet were glaciated in Pleistocene time.

GEOLOGY.

Algonkian sedimentary rocks, largely confined to the central part of the district, form the principal stratified rocks of the area. They are completely metamorphosed to quartzites, slates, and schists which, although varying greatly in attitude from place to place, in general dip 45° ENE. They occur as a broad outlier resting upon the granite which is extensively exposed in the canyons bordering the area.

Miocene lake beds occur in Moose Creek basin as a small area about three-fourths of a mile wide and 5 miles long. They are excellently exposed at the head of Dump Creek canyon, which is the lower continuation of the valley occupied by them. As here seen, the beds are more than 200 feet thick, consisting of about 100 feet of rhyolite flows overlain by conglomerate at the base, followed by thinly bedded alternating layers of sandstone, shale, and lignitic material for about 100 feet more. After these were tilted to a dip of 10° E. and a central trench was developed through the basin, basalt poured into the lower parts, making the surface nearly level. Then followed a thin veneer of auriferous gravels. Some time during its later history the drainage changed from its normal outlet by way of Dump Creek and escaped by way of Moose Creek. The divide remained so low, however, that during early placer mining Moose Creek was returned to its original outlet and now escapes through a deep trench, excavated by it in recent years. (See fig. 7, p. 36.) A dike of rhyolite porphyry, which crosses the valley below the deposit, probably formed the dam that caused the Miocene lake.

Granite gneiss, resulting from intense metamorphism of a coarse-textured biotite granite, is exposed in the northwest part of the district. In most exposures the gneiss is readily recognized by its large feldspar crystals, many of them 2 or 3 inches in length, which are somewhat drawn out and interspread between fine-grained bands of intimately mixed biotite and quartz. The rock is of Archean age and constitutes the basement upon which the Algonkian sedimentary rocks rest.

The next younger igneous rock is a medium-grained biotite granite which cuts both the gneiss and the schists. From the gneiss it is readily distinguished by its general lack of schistosity, its more nearly equigranular texture, and its generally fresh appearance. The rock is exposed as a broad band surrounding the large area of Algonkian sedimentary rocks which occupy the central part of the district. Along the inner side of the eastern portion its contact with the

sedimentary rocks is a fault plane, but in most places it is clearly intrusive and accompanied by garnet, epidote, and chiastolite developed in the older rocks near its contact.

Dikes are not numerous in those parts of the Mackinaw district which were visited. One of rhyolite porphyry occurs near the head of Dump Creek and two or three others at the mouth of Phelan Creek. Near the Italian mine a dike of biotite monzonite 100 feet wide strikes N. 60° W. The rock is dark gray and equigranular and contains about equal amounts of oligoclase and orthoclase (Pl. VIII, A, p. 45). together with much biotite.

Lavas are developed along Moose Creek and along Napias Creek, near the mouth of Phelan Creek. In the former locality they consist of rhyolites which underlie the lake beds, and basalts which overlie them. In the latter area both rhyolites and basalts are seen, the former greatly predominating. The relative ages of the lavas as here exposed were not determined. In each locality their areal extent is about 4 or 5 square miles.

PLACER DEPOSITS.

Placers have been worked along Napias Creek and its tributaries, Moose Creek and Beaver Creek. They occur above 6,500 feet elevation, except on Beaver Creek, where they extend down to 3,500 feet above sea level.

LEESBURG BASIN.

Napias Creek and its tributaries drain an area commonly known as the Leesburg Basin, which comprises about 1,000 acres of ground. This ground includes the most extensive placers in the Mackinaw district and the earliest discovered in Lemhi County, being located in July, 1866. Work has been carried on almost entirely by hydraulic methods and a total of possibly \$5,000,000 has been recovered. The gravels vary from 5 to 8 feet in thickness and range from pebbles to boulders 10 inches through, with a few up to 4 or 5 feet. In most of the workings decomposed granite is the bedrock, but in places, particularly on Phelan Creek, the gravels overlie glacial till. One mile below Leesburg two beds of gravel separated by about 8 feet of glacial till have been recognized, but only the upper bed has been worked. Most of the gold occurs in the first 18 inches above bedrock, in coarse and fine grains, although some small nuggets and a few worth from \$15 to \$20 have been found.

Placer mining has been practically abandoned in the Leesburg Basin for many years, only a few individuals operating intermittently. An area of special interest is on the hill near the Haidee mine, where the arkosic mantle formed each winter by the disintegration of granite is washed for gold each spring and affords wages, though little more.

MOOSE CREEK.

Next in importance among the placer grounds in the district are those along Moose Creek, where 200 acres have yielded about \$1,000,000. This deposit has continued productive down to the present, the annual production for several years past having been about \$20,000. This property, located a short time after the Leesburg placers, was owned and worked for many years by David McNutt, of Salmon. In 1898 it passed into the hands of the Pacific Dredging Co., of Chicago, and was operated with a dredge for four and one-half years. Later it was secured by John E. Mullen, who for the past four years has operated a dredge of 2,000 yards daily capacity. In addition to the main deposit, Beartrack, Webfoot, and Dailey Creek gulches, all tributary from the east, have produced noteworthy amounts of gold.

The basement is an even floor, in places formed of decomposed granite but mostly of Miocene lake beds, themselves largely arkosic, and thus sometimes mistaken by the miners for decomposed granite. Where work has been done the overlying gravels have been found to vary in thickness from 10 to 18 feet, but near the head of the basin test pits show them to attain a thickness of 30 feet. The deposit is made up of waterworn granite and quartzite fragments, few of them more than 8 inches in diameter, averaging perhaps 4 inches, in general loosely cemented. The gold, worth about \$19 per ounce, occurs as coarse and fine grains and is largely confined to the lower 12 inches of the gravels and the upper 18 inches of bedrock. Most of it is found in the joints, depressions, and loosely assembled parts of the latter. In its areal distribution the pay streak swings from one side of the basin to the other, like the meanders of a stream.

BEAVER CREEK.

Near the confluence of Beaver Creek with Big Creek placers have been worked intermittently for a number of years, producing somewhat less than \$100,000. They have been recognized at three levels, the lower being the recent accumulations along the valley flats, the upper a terrace northeast of the point of intersection of the streams and 400 feet above them, and the intermediate a terrace on the same slope, 100 feet above its base. Most of the production has come from the upper terrace. Considerable drifting and shaft work has been done on the valley level, where the gravels are about 80 feet thick, but without profit. Bedrock is granite gneiss, depressions in which are said to determine the pay streaks.

SOURCE OF THE PLACER GOLD.

In many places in the district the source of the placer gold has been definitely located. The Beaver Creek placers from their distribution were evidently derived from the upper part of Beaver Creek canyon,

and here the Mayflower and other veins are recognized. Those of Leesburg Basin were derived from the area to the west, for, except for Phelan Creek, which is south of the principal workings, only tributaries from the west have yielded placer gold. Up the several gulches on the west side are situated the Italian, Haidee, Gold Ridge, Gold Dust, and Gold Flint mines, all of which are held for free gold, whereas, on the east side of the basin, no veins have been worked. On the other hand, the Moose Creek placers extend only up valleys tributary from the east and south, and on all of these the source of the gold is not clear, for but one vein, that of Shoo Fly mine, has been located to the east. To the south the northward continuation of the Gold Flint lode is recognized.

AGE OF THE PLACERS.

The placers of the district occupy erosion basins formed after the elevation of the Eocene erosion surface. (See p. 53.) The earlier and more extensive probably accumulated during both Miocene and Pliocene time. A break during the Pleistocene is recorded by a bed of pulverized rock, 8 to 10 feet thick, which is clearly of glacial origin. After the glacial epoch gravel accumulation continued, as shown by bedrock of glacial till in the deposits on Phelan Creek, by some of the deposits on Camp Creek, and by deposits in some parts of the main valley near Leesburg post office. The area around the Haidee mine, where the thin mantle formed by the disintegration each winter of the already deeply weathered granite bedrock is washed for gold each spring, indicates that the accumulation of placer gold still continues in the area.

LODE DEPOSITS.

DISTRIBUTION.

The most important known lode deposits occur west of Leesburg in the granite area, north of Leesburg along a fault plane between granite and metamorphosed sediments; northeast of the Moose Creek placers in the Algonkian sedimentary rocks, and in the vicinity of Beaver Creek, in the old sedimentary rocks. In general, the lodes strike north and south and dip west.

VEINS.

The deposits occur as (1) quartz veins accompanied by stockwork in granite; (2) replacement veins along fault planes; (3) replacements along shear zones; (4) lenses in schist; and (5) veins in contact with biotite monzonite dikes. As is common, the several types grade into each other, and it would be difficult to determine which of them has been most important in yielding placers, although the third is clearly

subordinate in importance to the others. The deposits of the first type have been most productive, and if plans for working the metallized granite adjacent to the veins prove a success they will be even more productive in the future.

The Italian mine and properties adjacent represent the first type. Here a fractured zone in granite extends for at least 5,000 feet in a north-south direction and dips about 45° W. In a few places quartz veins are as much as 3 feet wide, but they do not average more than 8 or 10 inches. Although the larger veins follow the north-south course and dip west, the innumerable quartz stringers, few of which are more than a fraction of an inch wide, traverse the granite in all directions, following fracture lines. In the quartz and in some crevices in the granite, almost to the exclusion of quartz, are pyrite, sphalerite, specularite, a little galena, and some manganese. In the past the quartz veins have been worked exclusively, producing about \$175,000, but recently treatment of the metallized granite, said to run from \$2 to \$4 a ton, has been attempted. A test run of 4,000 tons which plated \$2.25 a ton was mined and milled at a cost of 87 cents a ton. The few specimens secured indicate that this granite is not greatly altered, the feldspars being comparatively fresh and the metallization largely confined to fracture planes.

Replacement veins along fault planes—deposits of the second type—occur in the Gold Dust, Gold Reef, and Gold Flint mines. Here metamorphosed sediments constituting the hanging wall of the vein have been faulted against granite. Heavy gouge which accompanies the fault in most places is sparsely metallized, but next to it and continuing out into the hanging wall, locally for 20 feet or more and as a much narrower band on the footwall, wide coarse pyritiferous quartz is developed. The amount of gold in the ore varies with the amount of pyrite present, the latter being very irregular in distribution. Aside from the quartz the only minerals noted in these deposits were pyrite, and iron and manganese stains.

The third type—replacements along a shear zone—occurs on the Mayflower group on Beaver Creek, where irregular replacements of pyritiferous quartz follow a disturbed zone which extends N. 30° W. The country rock is siliceous schist. A similar occurrence is Copper King vein. In both garnet, accompanied by epidote and magnetite, appears in the inclosing rock.

Lenses in schist and probably also in granite—the fourth type—appear to have been the source of much of the placer gold found on Moose Creek. The country within the Moose Creek drainage basin and east of the placer ground was not examined during the reconnaissance, but as auriferous gravels are reported up the gulches which extend in that direction and do not appear along those leading west, most of the gold probably came from the east. The only property

located on that side is the Shoo Fly vein, which is of the fourth type. Quartz stringers, however, are reported from the granite area south and east of the placers.

Ore occurs in contact with a biotite monzonite dike—the fifth type—on the Italian property. The vein, which is about 2½ feet wide and which consists of coarse-textured bluish-white quartz, lies on the footwall side of the dike. It differs from all other veins in the district in the variety and relative importance of the minerals present. Chalcopyrite is most important and sphalerite comparatively abundant; pyrite and galena are subordinate in amount and are distributed irregularly and rather sparsely through the gangue. This deposit cuts deposits of the first type—quartz veins accompanied by stockwork in granite.

Lead ores have been reported recently from a property called the Bull of the Woods near Leesburg, but their extent and character are as yet undetermined.

AGE AND GENESIS.

All the lode deposits in the district are probably of about the same age, the vein accompanying the biotite monzonite dike being assigned to a later stage of the same general period. Throughout the deposits coarsely crystallized quartz is characteristic; in some garnet, epidote, and magnetite accompany the ores; in all pyrite is present, and more or less replacement of wall rock has taken place. These general characteristics clearly indicate deposition under conditions of intense heat and pressure. The deposits occur both within the metasediments and within the granite, but in both near the contact between these types of rock. An inspection of the map (Pl. I, in pocket) brings out very strikingly this relation. In no place do they occur either in the sediments or in the granite at a greater distance than 2 miles from the contact.

These facts strongly suggest that the deposits are genetically related to the granite magma and are in accord with a view that the solutions emanated from that mass after its outer part had solidified. As the granite is of late Cretaceous or early Eocene age, and as from physiographic evidence the deposits are older than late Eocene, it is concluded that they followed closely the intrusion of the granite.

MINES.

ITALIAN MINE.

The Italian mine is situated on Arnett Creek 3½ miles from Napias Creek and at an elevation of 7,150 feet above sea level. (See Pl. XXI, A.) The property was located in 1892 by three Italians and operated by them until 1904 when it was purchased by the Leesburg Mining Co. Recently this company has built a 30-stamp mill and installed a 700-horsepower electric plant on Big Creek at a point 7



A. ITALIAN MINE

Showing 30-stamp mill and location of principal workings.



B. CAMP OF ULYSSES.

Kettle Burton mill on right.



miles west from the mine. Development consists of some 3,500 feet of tunnel and a shaft 240 feet deep and of a great many open cuts and 80 acres of placer diggings. The total production of the property, exclusive of the placers, is about \$175,000, most of which was extracted in a 10-stamp mill prior to 1904. A trial run of 4,000 tons in the new mill in 1910 plated \$2.25 per ton at a total cost for mining and milling of 87 cents per ton.

The country rock is the normal biotite granite, in many places greatly fractured and heavily stained with iron. Cutting the granite in a N. 60° W. direction is a dike of fine-grained dark-gray equigranular rock, made up of biotite and orthoclase together with a little oligoclase and micropegmatite. The type is uncommon, but the rock should probably be classified as biotite monzonite (p. 45). The granite, when heavily fractured and iron stained, weathers very rapidly, breaking down to an arkose which is auriferous in many places.

The ore occurs in a north-south zone about 5,000 feet in length and up to 300 feet or more in width. In this zone occur innumerable quartz stringers and a few narrow quartz veins, the latter usually irregular in width and very limited in extent. The veins have afforded most of the production, but it is the intention of the present company to work the mineralized granite, said to run from \$2 to \$4 per ton. The principal ore minerals are pyrite, less sphalerite and pyrolusite, and a little galena. In the veins the metallic minerals are irregularly distributed through a coarse bluish-white quartz; in the granite they constitute almost the entire filling of some of the narrow joints and fractures, or are intermixed with vein quartz. The single specimen of granite studied microscopically is remarkably fresh, the feldspars being little altered, although in places the biotite is bleached. The striking feature is the great number of cracks which traverse the section in every direction. Along them iron stains are common and in places sericite has developed. In the hand specimen specularite also was noted, although none appears in the slide. Accompanying the biotite monzonite is another type of deposit—a coarse-textured quartz vein about 2½ feet wide, lying on the footwall side of the dike. It differs from the other deposits in carrying chalcopyrite but contains almost as much sphalerite and a little pyrite and galena. The dike and accompanying ore cuts the other deposit.

HAIDEE MINE.

The Haidee mine, situated 1½ miles north of the Italian mine, is similar to it in geologic relations and character of ore. Development on the property consists of a shaft 160 feet deep with 400 or 500 feet of drifting from it, and a tunnel 3,000 feet long which, because of caving, was abandoned before the vein was reached. The vein, which is inclosed in granite, strikes north and south and dips

57° W. It is a fissure filling 3 to 4 feet wide. The quartz is coarse textured, and carries irregularly spaced heavy bands of pyrite cubes, some of them 3 or 4 inches wide, in places constituting as much as one-third of the vein matter. Intermixed with the pyrite is a little sphalerite and a very little galena. Manganese oxide is abundant. The ore is said to have plated about \$7 per ton in gold.

SHOO FLY MINE.

The Shoo Fly ledge, the first location in the district, was discovered through large and high-grade boulders of vein matter strewn along the hillside below its outcrop. It was made up of irregular lenses of quartz inclosed in "schist." Although the ore was high grade in places, it never gave satisfactory returns. About \$75,000 is said to have been produced, chiefly from the residual quartz boulders.

GOLD FLINT MINE.

The Gold Flint mine is situated $1\frac{1}{2}$ miles north of Leesburg. The property was located in 1880 and some ore has been blocked out but no bullion produced. The vein, which is developed by about 1,200 feet of tunnels, occurs along a fault plane which strikes N. 18° E. and dips 45° NW. It throws Algonkian sedimentary rocks against late Cretaceous granite. The deposit is of replacement origin, the best ore occurring next to the heavy gouge which accompanies the fault plane, and from there grading out into the sediments, so that in most places about 20 feet is visibly mineralized. The minerals noted were pyrite and manganese and iron oxides. Gold, accompanied by some silver, is claimed in amounts of about \$5 per ton.

It is worthy of note that the Wards Gulch placers, which produced about \$1,000,000, extend headward to the intersection with this deposit but not farther; also that the placer-gold found here differed from that in most other parts of the Leesburg basin in the high percentage of silver present, an amount sufficient to reduce the gold content to \$14 an ounce. These facts are in perfect accord with the idea that the placers of the Leesburg basin were derived from the Gold Flint ledge and the several others south of it.

GOLD DUST MINE.

The Gold Dust mine is situated across Wards Gulch, south of the Gold Flint mine, and in its broader features is similar to that deposit. The ore either follows a fault parallel to that in the Gold Flint mine or the same one which has been offset to the east in its southern part by a cross fault along the line of Wards Gulch. The ore bodies are considerably broken and mineralization is not intense. A 10-stamp mill, which ran about 90 days, is situated on the property.

GOLD RIDGE MINE.

The Gold Ridge mine is situated on the same fault zone as the Gold Flint and the Gold Dust. It is developed by about 1,000 feet of tunnel and raises. A 10-stamp mill and a 50-ton cyanide plant which operated for parts of two years are situated near the principal portal. The ore is low grade, probably running \$2 to \$3 a ton.

COPPER KING MINE.

Copper King Mountain, on which the Copper King property is situated, rises a few hundred feet above the plateau area, 13 miles northwest of Leesburg. Development consists of about 500 feet of tunnel and shaft work. The country rock is quartzite, locally including garnetiferous mica schist; it strikes N. 25° W. and in general dips about 45° NE., whereas the vein strikes N. 45° E. and dips 75° NW. The latter, which averages perhaps 2 feet in width, is accompanied by many parallel stringers separated from each other and from it by mineralized wall rock. The mineralized zone thus defined is some 40 feet across. The quartz near the surface has been intricately fractured and generally leached of its metallic content. In the lowest workings, about 200 feet below the surface, the minerals noted are scattered pyrite, chalcopyrite, and magnetite, and abundant oxidation products from them.

MAYFLOWER GROUP.

The Mayflower group includes three patented claims situated at an elevation of 5,200 feet on the south wall of Beaver Creek canyon, about 3½ miles above its junction with Big Creek. Little work has been done on the deposits, which consist of replacements along a brecciated zone in siliceous schist. In some places, owing to leaching of pyrite and chalcopyrite, the quartz is extensively honeycombed but in others it is not metallized. The brecciated material accompanying the quartz is locally almost entirely made up of garnet with associated epidote and magnetite. The property is held for copper, gold, and silver.

EUREKA DISTRICT.**SITUATION.**

The Eureka mining district includes a narrow strip of country extending along the western side of Salmon Valley, possibly 15 miles above and an equal distance below Salmon. Westward it extends to the crest of the mountain slope, and eastward Salmon and Lemhi rivers may be taken as the boundary. It thus includes the north end of Lemhi Range. Moose Creek, beyond the summit to the northwest, is sometimes included in the Eureka and sometimes in the Mackinaw district, but as its deposits can be more advantageously

described with those of the latter area, it is discussed in connection with them. (See p. 149.)

The mining of the precious metals is confined entirely to lode deposits. Many claims have been located, but even collectively they have afforded but little bullion, \$150,000 being a liberal estimate for the total production. If, however, Moose Creek is included in the district, the estimate should be increased by about \$1,000,000.

TOPOGRAPHY.

In its southern part the district is trenched to a depth of 4,000 feet or more by Salmon River. Northward the western wall continues for the full width of the district; the eastern one, however, swings east, forming the end of Lemhi Range and thence continues southeast. Indenting the otherwise regular slopes of the mountains are many deep narrow gulches, rounded by glaciation in their upper parts, but narrow and V-shaped below.

GEOLOGY.

Both Algonkian quartzites and Miocene lake beds are exposed in the area, the latter along the lower mountain slopes and the former in their upper reaches. The older rocks are predominantly dark-gray quartzites which in general strike north and south and dip east, although locally the dip is to the west. Overlying these below an elevation of 5,700 feet are the Miocene beds, made up of indurated clays and sandstones, and a very few beds of conglomerate. Perhaps 1,500 feet of these beds is exposed in the area. In their lower part they are commonly light gray, but above are conspicuous beds of maroon color.

The gray granite intrusion, widely exposed in the Mackinaw district, extends into the northwest part of the Eureka district. The rock is readily distinguished by its gray color, medium to coarse granular texture, fresh appearance, and constituents—orthoclase, quartz, and biotite. It is probably of late Cretaceous or early Eocene age. From early Eocene to middle Tertiary no igneous activity is recorded, but since then there have been several periods of eruption. A rock, noteworthy because it has been recently, though not successfully, exploited for aluminum, is exposed along Jesse Creek west of Salmon. It is dull white with phenocrysts of euhedral quartz scattered through a greatly decomposed groundmass. Although the feldspars are too greatly altered for identification, it is thought that the rock is rhyolite. It is inclosed in the lake beds just below the maroon shales. The lavas of the district are best exposed in its southern part at the entrance to Salmon Canyon, where two thick flows of rhyolite are separated by massive andesite. The three,

possibly aggregating 1,200 feet in thickness, are apparently conformable and dip 10° to 20° N. Yet another type of eruptive occurs in a small area near the summit of Baldy Mountain. It is a basalt, fine grained and of greenish-black color.

ORE DEPOSITS.

Both gold and copper ores are found in the district, but neither has proved very important, and only the gold has been mined. During the spring of 1910 several claims were staked in the area of the lake beds west of Salmon, and a company was formed, capitalized at \$2,000,000, for the purpose of extracting aluminum from material found in this locality. The rock is a decomposed eruptive, probably rhyolite. It is hardly necessary to say that aluminum has not been extracted in commercial amounts. Coal of sufficient purity to find a local market has been worked to a limited extent on Jesse Creek (p. 83).

The properties held exclusively for gold lie high up on the mountain side northwest of Salmon in a belt about 6 miles long. They include the U. P. & Burlington, Queen of the Hills, and Tendoy mines. In each the ore occurs as veins in granite, near its contact with quartzite.

Two parallel veins have been recognized in the northern part of the belt, three in the central part, and one in the southern. Within the deposits, which are bounded by parallel walls 5 to 10 feet apart, gouge and quartz are found. The quartz is coarse and occurs as lenses, stringers following the hanging or foot wall, and fillings between blocks of gouge. In few places, however, does it constitute as much as one-third of the entire filling. Within the veins the ore occurs in shoots which in general pitch more than 45° S. Of the metallic minerals which occur within them, pyrite is most important, chalcopyrite is generally present, and galena is rare. These minerals occur in isolated crystals, irregular bunches, and in some places in parallel bands. The gold seems to vary in amount with the pyrite. The workings are all within the zone of oxidation, so that the primary minerals are seen only in protected places; in their stead limonite, bornite, malachite, azurite, and possibly cerusite are present. Manganese stains are common in the ore.

The copper deposits are inclosed in schists and quartzites. They lie south of Salmon, both east and west of the river, and where seen comprise quartz fillings and impregnations along sheared zones. In general these deposits are poorly defined, within them scattered bunches and films of chalcopyrite, in many places changed to bornite, malachite, or azurite, constitute the principal mineralization.

The type of ores found in the Eureka district and their mode of occurrence leads to their correlation with the deposits of the Mackinaw district, which are believed to be of late Cretaceous or early Eocene

age (p. 152). Like the Mackinaw deposits, those of the Eureka district are thought to be genetically related to the granitic intrusion.

MINES.

QUEEN OF THE HILLS MINE.

The Queen of the Hills mine, owned by the Copper Queen Mining & Smelting Co., is situated 7 miles northwest from Salmon at an elevation of 5,800 feet on Dryer gulch. Location was made in the early eighties but active development did not commence until 1898. Since then, about 9,000 feet of work has been done, the mine being opened on five levels and to a maximum depth of 400 feet. The production is about \$80,000 in gold bullion, most of which has been extracted by a 15-stamp mill situated on the property.

Three veins, all in granite, have been explored. They strike N. 27° E. and one (Queen vein) dips 80°–85° SE.; the other two (Nellie and Eva veins) dip in the opposite direction at about the same angle. The Eva, the most westerly vein, occurs as a band of quartz 8 to 14 inches wide, following one or the other wall of a 5-foot brecciated zone. The Queen (the central vein) follows a zone about 12 feet wide, possibly one-half of which is made up of quartz, either as distinct bands or filling interstices between granite fragments. The Nellie vein is similar to the Queen.

The ore occurs in shoots, five of which have been found—two in the Nellie vein, two in the Queen, and one in the Eva. They all pitch from 45° to 55° S. In them the quartz is of the coarsely crystalline variety common to all parts of the vein, but scattered through it irregularly are crystals of pyrite, chalcopyrite, and a little galena, together with their oxidation products, chief of which are limonite and malachite. Gold is thought to be associated with the pyrite, for it is said to vary in amount with that mineral. The average gold content for the Eva shoot is said to be \$3.50 per ton, though in a small stope near the surface the average was \$18 and in another on the fifth level it was \$19.40 per ton. The better ore in the Nellie vein is said to run from \$5 to \$8.

U. P. & BURLINGTON MINE.

The U. P. & Burlington mine is situated at an elevation of 8,600 feet on the mountain slope west of Salmon. Development includes six tunnels, distributed up the mountain side at elevations 100 feet apart, and a shallow shaft beyond the upper one, in all about 2,000 feet of work. A 10-stamp mill, which has treated a small tonnage of ore, is situated on the property. The total production is perhaps a few thousand dollars, \$800 having been derived from the last mill run of 40 tons.

The vein, which strikes N. 42° E. and dips 80°–87° NW., lies in the granite about 100 yards from its contact with the quartzites. The walls are firm and about 5 feet apart, the interim being filled with coarse gouge and vein matter. In most places the vein is about 10 inches wide, but locally it widens to 2 feet or narrows to a stringer. In some places it is split into two or more parallel bands, separated by gouge. The quartz is clear and coarsely crystalline and contains a few vugs lined with crystals of the same material. Pyrite occurs in coarse isolated cubes, bunches of cubes, and in a few fine-grained bands. It varies greatly in amount, in places constituting as much as 15 per cent of a face, and in others being entirely absent. It is claimed that 1,000 tons of ore of milling grade are blocked out.

JOHN TORMEY GROUP.

The John Tormey group of claims is situated 7 miles south of Salmon and 3 miles up Corral Creek, on the north side. Development consists of two tunnels, each about 225 feet deep, and several small prospect openings. The tunnels are about a half mile apart and on different lodes. Both are in Algonkian schist and quartzite, the ore occurring along a disturbed zone as small quartz veins, as fillings of the interstices, and as impregnations in the schist.

The deposits strike N. 35°–60° W. and dip northeast at high angles. Rather sparsely and irregularly scattered through the lode material are pyrite usually changed to limonite, and chalcopyrite usually altered to malachite, azurite, or bornite. The claims are held for copper.

TENDOY MINE.

The Tendoy mine is located 2 miles north of the Queen of the Hills mine. Two veins, developed by about 400 feet of tunnels, have been worked and a small amount of bullion recovered with a 2-stamp Nissen mill located on the property. This mine was not visited, but it is stated that the ore and its occurrence is similar to that at the Queen of the Hills.

OTHER PROPERTIES.

Several prospects are situated on the north end of Lemhi Range along its middle and upper slopes. None of these has produced and only a little development has been accomplished. Both gold and copper are reported.

BLACKBIRD DISTRICT.

SITUATION AND HISTORY.

The Blackbird mining district, situated in the west-central part of Lemhi County, merges by indefinite boundaries into the Mackinaw district on the north, the Eureka district on the east, and the Yellow Jacket district on the southwest. The area is traversed by the

Salmon-Forney stage road, from which branches extend up Blackbird and Musgrove creeks. Salmon, 35 miles to the northeast, is the supply point for the district.

The district was discovered in 1893 and most of the claims were located during the three years following. (See Pl. XXII.) All the properties were held for gold until the latter part of 1896, when copper was recognized in workable amounts. In 1899 twenty-nine claims were bonded by the Blackbird Copper-Gold Mining Co., and during the next two years about 1,400 feet of development work was done. The group was then patented and work was suspended. Cobalt and nickel were first taken into account in 1901, when John Beliel, of Leesburg, located a group of fourteen claims along the west fork of Blackbird Creek. Although mining operations have been at a standstill for the past 12 years, a small group of men have lived in the camp continuously and hold ground adjacent to the principal property. The production of the district is confined to a few mill and smelter tests.

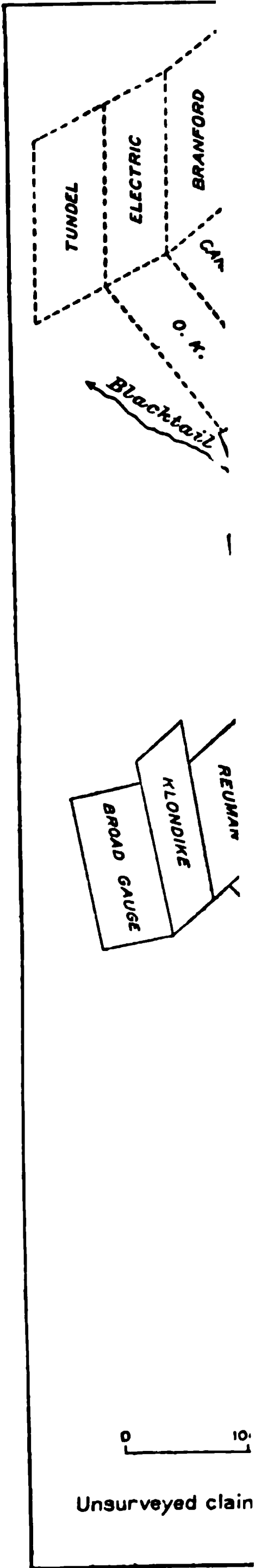
TOPOGRAPHY.

The district comprises a heavily wooded and deeply trenched tableland 7,500 to 8,000 feet above sea level. Blackbird Creek, after which the district is named, heads near the center of the area and flows east in a deep narrow valley some 7 miles long. Big Creek, the major drainage line, occupies a trench from 2,000 to 3,000 feet deep, which extends along the east and north boundaries. Other streams are Musgrove Creek, which flows east in the southern part of the district, and Little Deer Creek, which flows north in the northern part. All the streams live throughout the year and Big Creek affords opportunity for the development of considerable water power.

GEOLOGY.

The most widespread rocks of the area are mica schists and quartzites of Algonkian age. They are extensively though not intensely metamorphosed. In general recrystallization is complete, and in places garnet, epidote, and chiastolite are strikingly developed. On the other hand, crumpling is not conspicuous, and in many places, nearly always in quartzite areas, bedding structure may be easily recognized. In general the series strikes 60° – 80° E. and dips 40° – 60° NW. It is crossed by a strong joint system, which strikes N. 10° – 40° W. and dips about 80° SW.

The igneous rocks in the Blackbird district include granite, gabbro, lamprophyre (minette), rhyolite porphyries, and rhyolites. The normal biotite granite, widely distributed to the north, is exposed in the northeast corner of the area. Near its margin there is a decided decrease in the amount of quartz and an increase in the amount of microperthite. Gabbro dikes, mostly extending in a north and south



lodes or lenses and disseminations, which are largely due to replacement.

The Moose Creek veins are quartz fillings, some of which average as much as 4 feet in width. They have a general strike of N. 40° W. and are principally found on the steep northern side of the valley. The quartz, which is extensively fractured, is everywhere fine grained, and in places includes angular fragments of wall rock. No primary minerals were seen in the veins, but the presence locally of extensive iron and manganese stains along the fracture planes suggests that pyrite and some manganese mineral are distributed irregularly through the unaltered ore. Gold, with traces of silver, occurs in those parts where metallic oxides are most abundant. It is noteworthy that of the several veins recognized, only one has been found to contain the precious metal in sufficient amounts to constitute an ore. In this vein the principal shoot averages about \$20 a ton in gold.

The Blackbird and Little Deer Creek lodes differ markedly from the above in mode of occurrence and mineral assemblage. These deposits are distributed rather uniformly throughout the areas in which they occur. Though commonly lenslike bodies, they assume in places the broadly tabular form of veins, as on the Uncle Sam claim. Again, the deposits occur as bunches or disseminations along certain favored zones. On the Hawkeye group irregular bunches of ore up to 4 or 5 inches in diameter are sparsely scattered through a gabbro dike. Their prevailing strike is N. 10°–40° W. with dip about 78° SW., although it is not uncommon to find ore extending in a general east-west direction and dipping south. The Beliel lodes, perhaps most important among the cobalt-nickel deposits, strike N. 40°–50° E., and dip 70°–80° SE. The deposits are predominantly of replacement origin, most of the metallic minerals being distributed as bunches, lenses, or disseminations along ill-defined zones in the country rock. (See Pl. XII, p. 71.) Elsewhere irregular veins, stringers, and lenses of coarsely crystalline quartz contain the ore minerals.

ORES.

Most conspicuous among the minerals of the district are the oxidation products of copper, iron, manganese, cobalt, and nickel, each of which is of striking color; malachite, the deep-green copper carbonate; limonite, the yellow hydrous iron oxide; pyrolusite, the dull-brown manganese oxide; erythrite, the pink to pearl-gray cobalt bloom; and annabergite, the pale apple-green nickel compound. Knowledge is largely lacking in regard to the cobalt and nickel ores, but is fairly definite as to the others. Iron occurs in pyrite, pyrrhotite, arsenopyrite, and less commonly in magnetite. A specimen of siderite was examined from the northern part of the area, but whether

it is primary or secondary is not known. Beautiful botryoidal hematite occurs in the oxidized ore of the Big Chief claim. The source of the secondary manganese is not clear, although rhodochrosite was seen in a few places in such relations as to suggest its primary origin. At least two cobalt minerals occur in the area, and both are probably primary. One is a reddish-gray mineral, probably cobaltite. In thin section (from Gray Eagle claim) it occurs as very small grains, bunched in very poorly defined lenticular areas, and replaces biotite and quartz in a garnetiferous biotitic quartzite (Pl. XII, B, p. 71). The other mineral, which affords the cobalt ore on the west end of the Beliel group, occurs as minute grains, fairly evenly distributed through the mass. Where most closely spaced they give the rock a steel-gray appearance, notably lacking the reddish hue of the cobaltite (?) described above. Although the specimens did not permit definite chemical tests, the color suggests smaltite. No primary nickel mineral, unless certain small indistinct crystals in the ore of the Togo claim are niccolite, was recognized; but in almost every place where nickel bloom appears pyrrhotite is present, thus suggesting that the nickel occurs as nickeliferous pyrrhotite—a relation borne out by analysis of a specimen of pyrrhotite (from the Togo claim) which gave 0.8 per cent nickel.

AGE AND GENESIS.

All the deposits of the district are inclosed in Algonkian schists and quartzites or in basic dikes which cut them. Thus, the nature of the inclosing rock throws little light on their age. Those on Musgrove Creek, however, from their crustification, lack of evidence of replacement, fine-grained quartz, and general association with rhyolite dikes, are considered much younger than those on Blackbird and Little Deer creeks. The latter are due largely to replacement, contain much pyrrhotite, and some magnetite, have coarse-textured quartz gangue, and are exceptional in that traces of cobalt or nickel, or both, are nearly everywhere present. Both types of deposits, in that they occur far up on the sides of the valleys which probably date from the early Pliocene, are considered as of Miocene age or earlier. On the other hand, the nickel-cobalt ores are locally found included in gabbro, which is probably of later age than the granite. Thus, as the granite is late Cretaceous or early Eocene, it is fairly safe to place the two periods of mineralization between that time and the late Miocene, the veins on Musgrove Creek being much younger than the lodes of Blackbird and Little Deer Creek basins.

The gold veins on Musgrove Creek are clearly fissure fillings formed under conditions of comparatively low temperature and pressure, as shown by their fine-grained quartz, loose crustification, and the angularity of their included fragments. They probably accompanied or

direction, were noted in the central part of the area. They are blue-black holocrystalline rocks, consisting of hornblende, diopside, plagioclase, and biotite, with accessory pyrrhotite, pyrite, titanite, and apatite. The lamprophyre (minette) dikes also occur in the central part of the area. They are fine-grained dark resinous gray rocks, consisting of biotite and orthoclase accompanied by subordinate amounts of plagioclase and hornblende. They strike both north-south and east-west. Rhyolite porphyries and flows were noted in the southern part of the district. Several dikes of this material, which is a light-gray rock consisting of a finely crystalline ground-mass studded with medium-sized quartz crystals, cross the deep, narrow valley of Musgrove Creek and spread out as flows along its topmost slopes.

ORE DEPOSITS.

DISTRIBUTION AND DEVELOPMENT.

The ore deposits as now known are confined to a small area about the head of Little Deer Creek, the upper basin of Blackbird Creek, and an area about a mile above the mouth of Musgrove Creek. In the two former localities copper, cobalt, nickel, and gold are present, but in the latter only gold has been found. Few districts present a more general distribution of outcrops sufficiently attractive to lend reasonable encouragement to the prospector than are to be found in the north and central part of the zone of mineralization as thus defined. Float heavily stained by manganese, iron, and copper (and much of it also by cobalt and nickel) can be found almost anywhere about the heads of Blackbird and Little Deer creeks. On Musgrove Creek the float is stained only by iron and manganese, and is confined to the outcrops of definite veins.

There are about 150 claims in the district, some 40 of which are patented. A great deal of gophering and very little systematic prospecting has been done, and as a result little definite information concerning the continuity or tenor of the deposits is obtainable. The property of the Blackbird Copper-Gold Mining Co. is an exception, but its workings were under water at the time of visit. Prospecting has shown that mineralization is widespread, so that the need of the district at present is systematic exploration of the better showings in order to determine whether or not the deposits are of commercial value. The proximity of ground water to the surface has been a serious handicap to the prospector and has led to the abandonment of most shafts at depths of less than 30 feet.

VEINS.

Two distinct types of deposits are recognized: the Moose Creek veins or fissure fillings, and the Blackbird and Little Deer Creek

lodes or lenses and disseminations, which are largely due to replacement.

The Moose Creek veins are quartz fillings, some of which average as much as 4 feet in width. They have a general strike of N. 40° W. and are principally found on the steep northern side of the valley. The quartz, which is extensively fractured, is everywhere fine grained, and in places includes angular fragments of wall rock. No primary minerals were seen in the veins, but the presence locally of extensive iron and manganese stains along the fracture planes suggests that pyrite and some manganese mineral are distributed irregularly through the unaltered ore. Gold, with traces of silver, occurs in those parts where metallic oxides are most abundant. It is noteworthy that of the several veins recognized, only one has been found to contain the precious metal in sufficient amounts to constitute an ore. In this vein the principal shoot averages about \$20 a ton in gold.

The Blackbird and Little Deer Creek lodes differ markedly from the above in mode of occurrence and mineral assemblage. These deposits are distributed rather uniformly throughout the areas in which they occur. Though commonly lenslike bodies, they assume in places the broadly tabular form of veins, as on the Uncle Sam claim. Again, the deposits occur as bunches or disseminations along certain favored zones. On the Hawkeye group irregular bunches of ore up to 4 or 5 inches in diameter are sparsely scattered through a gabbro dike. Their prevailing strike is N. 10°–40° W. with dip about 78° SW., although it is not uncommon to find ore extending in a general east-west direction and dipping south. The Beliel lodes, perhaps most important among the cobalt-nickel deposits, strike N. 40°–50° E., and dip 70°–80° SE. The deposits are predominantly of replacement origin, most of the metallic minerals being distributed as bunches, lenses, or disseminations along ill-defined zones in the country rock. (See Pl. XII, p. 71.) Elsewhere irregular veins, stringers, and lenses of coarsely crystalline quartz contain the ore minerals.

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The gold veins on Musgrove Creek are clearly fissure fillings formed under conditions of comparatively low temperature and pressure, as shown by their fine-grained quartz, loose crustification, and the angularity of their included fragments. They probably accompanied or

closely followed the igneous activity recorded in the rhyolite dikes which occur in their immediate vicinity and which are thought to be of Miocene age.

The genetic relations of the Blackbird-Little Deer Creek lodes, on the other hand, are somewhat more definite. A gabbro dike about 50 feet wide has been prospected on the Togo claim. In places within it are bunches of quartz and calcite carrying biotite, in the form of rosettes up to one-tenth inch in diameter, intimately intermixed with pyrite and pyrrhotite. From the hand specimen it is impossible to make out whether these bunches are due to replacement in the gabbro or to magmatic differentiation, but when studied in thin sections the intergrowth of pyrite and pyrrhotite with biotite and hornblende is clearly seen and leaves little room to doubt that these metallic minerals are native to the magma. Chemical analyses of pyrrhotite thus occurring record the presence of 0.8 per cent nickel. Along the contact of this dike, and as stringers and bunches in the schist nearby, are nickel, copper, and cobalt ores, in all respects similar to those occurring elsewhere in the area. It is concluded, therefore, that the ores of this type are genetically related to the gabbro magma and were deposited largely as replacements in the greatly fractured metamorphic rocks which it intruded. They are thought to date from the late Cretaceous or early Eocene.

MINES.

BLACKBIRD MINES.

The Blackbird Copper-Gold Mining Co. has 29 claims in the central part of the district. Development consists of three shafts, exploratory drifts therefrom, and numerous small tunnels—in all perhaps 2,500 feet of work. Since going to patent, several years ago, the property has lain idle, so that the workings are now inaccessible.

The ore bodies, which are inclosed in Algonkian schists and quartzites, are irregular replacements along fracture zones, so distributed that in general outline they resemble veins. The ore is sought for copper and gold, a wide zone exposed in the Brown Bear workings near the west end of the group being said to average 3 per cent of copper and \$1.50 in gold to the ton.

BELIEL GROUP.

The Beliel group includes 14 unpatented claims situated between the main forks of Blackbird Creek, near their junction. Little development has been done on the property, although the position of the ledge along the rugged northern wall of the valley affords fairly satisfactory exposures.

The outcrops in many places present beautiful red, pink, and pearl-gray stains and incrustations—in one place so pronounced as to be

visible for a quarter of a mile or more (Pl. XI, p. 70). The ledge strikes N. 40°–50° E. and dips 70°–80° SE., thus approximating the strike and dip of the inclosing rocks. The ore consists of mineralized quartzite, rarely schist, which is more resistant to weathering than the unaltered rock and stands in bold outcrop. In it small grains of pyrrhotite and pyrite can be seen with the unaided eye; in thin section numerous specks of silver-gray color, possibly smaltite, appear irregularly scattered through the quartzite or schist which they replace. A sample from 20 feet across the ledge, as exposed by tunnel on the west end of the property, ran a fraction less than 2 per cent cobalt, and a similar face on the east end afforded 2 per cent nickel and less than 1 per cent cobalt.

MUSGROVE GROUP.

The Musgrove group consists of five claims situated on the north side of Musgrove Creek, a mile from its mouth. The veins are quartz fillings, varying from a few inches up to 4 feet in width. They strike N. 40° W., crossing the beds of the inclosing quartzites, which strike from N. 45°–60° E. Of several veins only one has been found to carry gold in commercial amounts. This vein is made up of fine-grained brecciated quartz heavily stained in places with iron and manganese. It is such material which constitutes the better grade of ore—ore averaging about \$20 a ton but in spots running as high as \$75. A considerable tonnage of this grade has been blocked out and plans are complete for installing a cyanide plant.

OTHER PROPERTIES.

Many groups of comparatively undeveloped claims are situated in the district. Most of them present strong surface indications, but it is thought that detailed descriptions of them would add little to the value of this paper.

YELLOW JACKET DISTRICT.

SITUATION AND HISTORY.

The Yellow Jacket mining district, comprising an area of perhaps three townships, is situated in the western part of Lemhi County, about 30 miles southwest of Salmon. It lies southwest of the Blackbird district and northwest of the Gravel Range district. A wagon road extends to Forney, 12 miles east, and thence north to Salmon and south to Challis, each about 50 miles distant. A trail leads west to Thunder Mountain. Mail reaches the camp triweekly from Salmon.

The Yellow Jacket veins, located in September, 1868, and worked by arrastres and a 5-stamp mill in the early seventies, were among the earliest, if not the earliest, lode deposits recognized in Lemhi

County. The principal mine, the Yellow Jacket, changed hands several times and was worked at intervals prior to 1897, when it was closed down and remained idle until the spring of 1910, at which time it was acquired by the Yellow Jacket Gold Mining Co., and work was resumed. A 10-stamp mill, erected in 1882, was displaced by one with 30 stamps nine years later, and the capacity of the latter was increased to 60 stamps in 1895. This mill is still standing, as is also one of 10 stamps on the Columbia property and one of 5 stamps on the Black Eagle group.

The production of the camp has come largely from the Yellow Jacket mine, which is said to have yielded about \$450,000, the average saving by amalgamation being \$5.50 per ton, or 92 per cent of the total content of the ore. In the early days placers were worked on Yellow Jacket Creek, but they did not produce much bullion.

The district has been briefly described by Eldridge,¹ who visited it in 1894 in connection with his reconnaissance across the State.

TOPOGRAPHY.

The Yellow Jacket district comprises a forest-clad mountainous area from 5,500 to 8,500 feet above sea level. The sides of the many deep valleys rise abruptly to the tops of rather even-crested ridges which form the divides between the major streams and extend out as bold spurs between minor ones. Yellow Jacket Creek, which flows southwest into Camas Creek, a tributary to Middle Fork of Salmon River, drains the area. It heads within the district and receives many tributaries along its course. Those of importance are Trail Creek from the east, two small streams from the northwest in the vicinity of Yellow Jacket, and Lake and Hoodoo creeks, which unite and enter the main stream about 5 miles below camp.

In the vicinity of the settlement the valley is somewhat wider than elsewhere, so that for a stretch of 1 to 2 miles a strip of comparatively level land, perhaps 1,500 feet wide, is available for building or other purposes. Yellow Jacket Creek and most of its feeders live throughout the year and afford abundant water for milling and other purposes connected with lode mining.

GEOLOGY.

Sedimentary rocks of Algonkian age prevail throughout the district. They are generally thin bedded and consist of crystalline schist, most of which is quartzitic, some micaceous, and a very little calcareous. Typical quartzite is subordinate, although one large area was noted in the vicinity of Black Eagle mine. The rocks are

¹ Eldridge, G. H., A geological reconnaissance across Idaho: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, pp. 49-54.

very uniformly metamorphosed, but little of the bedding structure is obliterated, and crumpling, even local crumpling, is rare. The structure is outlined effectively by Eldridge,¹ who writes as follows:

The entire region between Panther and Camas creeks, which includes the Yellow Jacket mining district, has been in former times one of great dynamic disturbances; folds, flexures, and faults, in addition to the intrusion of eruptives, occur. The structure is, therefore, difficult to determine, and the difficulty is increased by the similarity of the schists from the base to the summit, rendering identification of horizon impossible.

In general the structure seems to be developed along lines varying from N. 30°–40° W. but with local divergences up to N. 60° E. and N. 60° W. Dips are predominantly 35°–85° W., although some of 40°–60° NE. were noted along the Forney road, 1 to 3 miles west of the summit. Independent of the attitude of the rocks is a strong system of joints which traverses all parts of the area along lines N. 50°–60° E. Almost at right angles to these are other joints, generally less conspicuous but still readily recognized in most exposures. The strong northeast joints seem to have been lines favored both by mineralizing solutions and injected igneous material.

Granite does not outcrop in those parts of the district which were visited, but the many granite boulders which appear along Yellow Jacket Creek indicate that extensive exposures occur in the upper part of the drainage basin. Though not exposed at the surface in the immediate vicinity of the camp, it is of course possible that granite lies at no great depth, a possibility suggested by numerous dikes and by certain metamorphic phenomena scarcely assignable to their influence. A specimen of altered calcareous schist from the northeast corner of the Columbia mill contains many little veinlets of calcite, scattered quartz grains, pale-green hornblende, poikilitic scapolite (mizzonite), and a few flakes of biotite, each intergrown with or included in the other. Pyrite is sparsely distributed through the section. The above association of minerals, together with their structure, strongly suggests contact influence. None of the dikes, so far as noted, have effected such metamorphism, and none of them crop out within several hundred feet of the place where this specimen was taken.

Dikes are conspicuous in the Yellow Jacket district. Seventeen were encountered in a traverse of 4,500 feet east from the Columbia mill, and as many are said to occur west from it. With few exceptions they have entered along the strong joint planes which strike N. 50°–60° E. Scarcely less conspicuous than their number is their variety. They include, about in descending order of their numerical importance, rhyolite porphyry, granite porphyry, lamprophyre (minette), diorite, hornblende monzonite, and diabase. Eldridge¹

¹ Eldridge, G. H., op. cit., p. 51.

in the county, may underlie the camp at no great depth. In many places in Idaho there is evidence that mineralization accompanied this granite, and to the north in the Mackinaw district similar ores are confined to the granite margin, so that it seems probable that these deposits are genetically related to a near-by though concealed batholithic mass of granite.

MINES.

YELLOW JACKET MINE.

The Yellow Jacket mine, which has produced \$450,000 in gold, largely from ore averaging about \$8 a ton, is situated on the mountain side three-fourths mile north of the town of Yellow Jacket. It is the oldest lode deposit in the camp—perhaps the oldest in Lemhi County, having been located in 1868. Development consists of about 4,000 feet of tunnels, crosscuts, and drifts, which reach the ore on four levels, the most extensive of which is known as No. 2. In addition to the underground development, considerable open-cut work has been done. (See fig. 24.)

The rock inclosing the veins is fine-grained quartzite, in places almost free from impurities, but more commonly micaceous and clayey. The beds strike N. 30°–60° W. and dip about 50° SW. Heavy joints extend N. 50°–60° E. Two faults, both of which strike about N. 40° W. and dip southwest, have been encountered in the mine. The western fault throws the vein 175 feet west on the east side and the eastern is said to cause a further displacement to the west of 90 feet.

The vein, which is about 15 feet wide, strikes N. 50°–60° E. and in general dips 35° NW., although locally increasing to 60° or even 80°. Its outcrop is an iron-stained honeycomb quartz, as is also the vein material found in the present workings, all of which are well above ground-water level. Primary metallic minerals are seldom seen in the ore, but the heavy iron stains and the shape of the cavities in the quartz-calcite gangue indicate that pyrite is the principal primary mineral. Rarely a stain of copper carbonate is seen. As most of the mining and much of the exploration (fig. 24) have been west of the west fault, the present owners intend to explore that part of the vein lying east of it.

BLACK EAGLE MINE.

The Black Eagle mine is situated about 5 miles northwest of Yellow Jacket at an elevation of 7,500 feet, near the head of Hoodoo Gulch. The property was located some 15 years ago, but little work was done until its acquisition by the present owners in 1905. It is opened by 350 feet of development tunnel. A 5-stamp mill, which has treated about 500 tons of ore, is situated on the property.

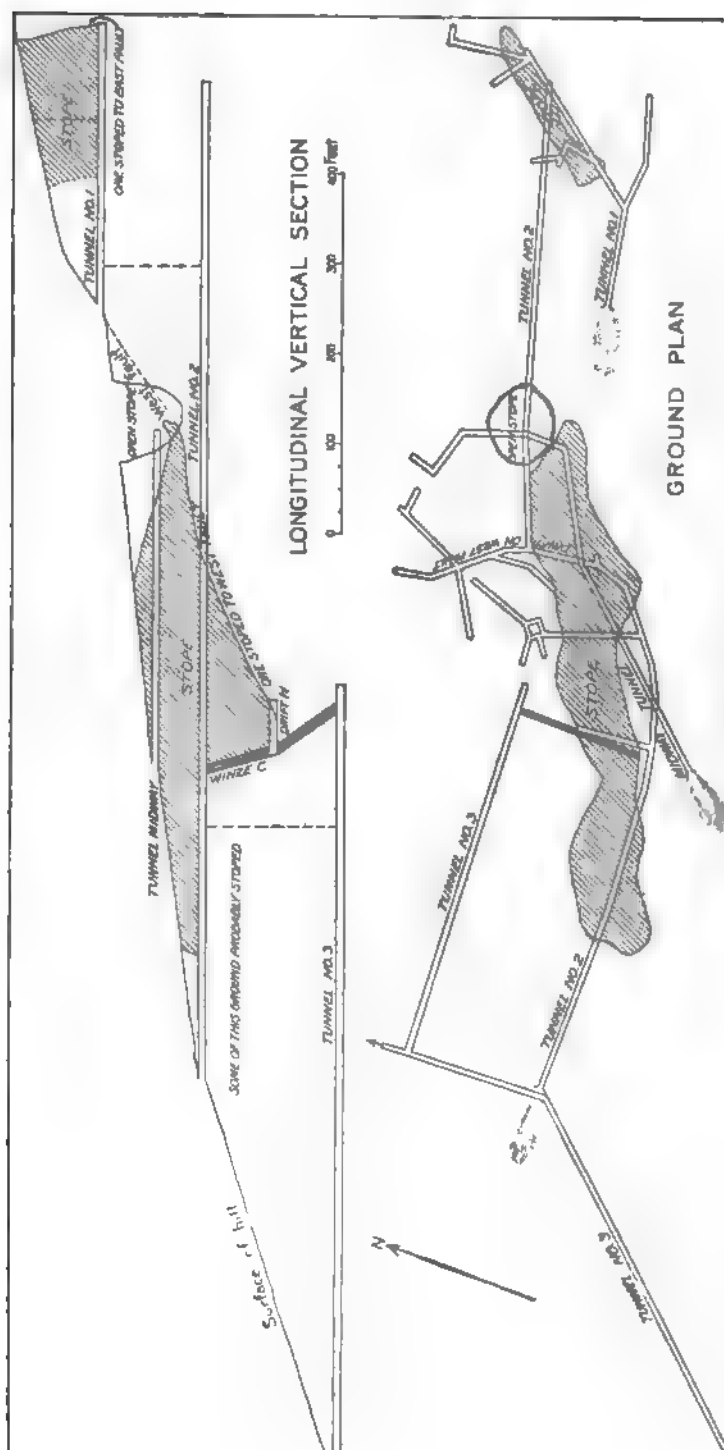


FIGURE 24.—Plan and projection of Yellow Jacket mine, Yellow Jacket district. A copy of the company's map on a reduced scale.

The country rock is a fine-grained, bluish-white quartzite which strikes N. 40°-50° E. and dips 70° NW. The ore is coarse quartz with pyrite, manganite, chalcopyrite, and a little sphalerite, scattered irregularly and generally sparsely through it. As exposed, the vein varies from a stringer up to 5 feet, averaging perhaps 6 inches. It is worked for gold.

RED JACKET MINE.

The Red Jacket mine is situated 1½ miles north of the town of Yellow Jacket, at an elevation of 7,700 feet. Two tunnels, neither of which was explored, appear on the property. As seen on the dump the ore is coarse quartz inclosing pyrite, chalcopyrite, sphalerite, and galena, decreasingly important in the order named. Oxidation is apparently slight in the deposit.

COLUMBIA MINE.

The Columbia mine is situated a mile west of Yellow Jacket. Development consists of four tunnels, totaling about 1,800 feet. A 10-stamp mill in connection with the property is said to have treated only a little ore. The workings were inaccessible at the time of visit, but Eldridge¹ states that the deposits are chalcopyrite-bearing quartz veins and impregnations, closely associated with a minette dike. The veins strike N. 60° E. The property is held for gold and silver.

GRAVEL RANGE DISTRICT.

SITUATION AND HISTORY.

The Gravel Range mining district is an ill-defined area of perhaps three townships, situated about 35 miles in a direct line southwest of Salmon. It lies southeast of the Yellow Jacket district and northeast of the Park Mountain district. Rabbitfoot and Myers Cove, the only settlements in the area, are respectively 9 miles south and 12 miles southwest of Forney, the present terminal of the Salmon stage line. From both of the camps wagon roads lead north to Salmon and south to Challis.

An arrastre was operated at Myers Cove (formerly called Singiser) in the early seventies, and about the same time gold was found at Rabbitfoot, where a little placer work was done. Substantial developments, however, did not commence in the district until 1896, when the present owners began to operate the Myers Cove property. Considerable ore, averaging about \$11 a ton, was soon blocked out and the method of treatment became vital. Amalgamation after roasting gave 11 to 20 per cent extraction; cyanidation gave 20 to 30 per cent; and a combination of chlorination and cyanidation yielded 70 to 90 per cent. A mill was built in keeping with

¹ Eldridge, G. H., op. cit., pp. 52-54.

these tests, but after running a month or six weeks it was abandoned as a failure. The Rabbitfoot properties were first actively developed in 1905 when a 10-stamp mill was built and operated for about six months. Prior to this a few Chinamen had worked placers along Silver Creek below Rabbitfoot, but with doubtful success.

The total production of the district is not known, but it is probably safe to assume that it is less than \$100,000.

TOPOGRAPHY.

The Gravel Range district comprises westward-sloping upland country, in most places 7,000 to 7,500 feet above sea level. In the western part it is dissected by the valleys of Silver and Arrastre creeks to a level 1,500 feet lower. About the southern border a serrate ridge of late Tertiary eruptives rises 1,000 to 1,500 feet above the general level, but to the north the surface grades into the high, gravel-covered, undulatory surface of the Prairie Basin. Silver Creek, the principal stream, heads south of Rabbitfoot, whence it flows northward and then southwestward. Its principal tributary is Arrastre Creek, which rises in a group of cirque basins near the south boundary of the district and flows northwest past the abandoned settlement of Myers Cove.

GEOLOGY.

Algonkian schists and quartzites, widely distributed elsewhere in the county, are exposed in only a few places in the district. Indeed, no outcrops were seen, although they are said to occur half a mile east and a mile south of Rabbitfoot. Their presence is indicated also by quartzite pebbles along the gulches heading in that quarter.

Boulders of diorite and of an equigranular rock, which when examined megascopically is strongly suggestive of quartz monzonite, were noted in a few places along the gulches near Rabbitfoot. Rhyolites predominate at the surface throughout the district. They are widely exposed to the northwest and are said to extend southwestward without a break to and beyond Parker Mountain. Associated with them are a few thin beds of trachyte and considerable thickness of volcanic tuff. At Rabbitfoot the rhyolites may be grouped into earlier and later, the two separated by a structural as well as by an erosional unconformity. Near the mine the earlier rhyolite flows strike N. 10°–20° E. and dip 40°–75° NW., and the later strike a little north of west and dip 30° N. The earlier flows are individually much thicker than the later and are usually extensively jointed. The later consist, from bottom upward, of a bed of volcanic mud and soil with included carbonaceous matter, in all about 20 feet thick. This is followed by a 6-foot flow of rhyolite overlain by 100 feet or more of rhyolite tuff, which in turn is covered

by a thick flow of rhyolite. The contact between the earlier and the later groups was seen in a placer bed 100 feet north of No. 1 portal and in the north drift of No. 2 tunnel. Elsewhere in the district lavas of two ages were not distinguishable.

The typical rhyolite is a light-gray rock consisting of orthoclase crystals and quartz grains set in a very fine grained groundmass. Wavy lines of flow structure are generally pronounced. Trachytes, nowhere conspicuous, resemble the rhyolites but have less-pronounced flow lines and no quartz grains. The rhyolitic tuffs are widely distributed, and locally are as much as 100 feet thick. They appear as chalky white exposures, with crude bedding, and their constituent particles are angular in outline.

The lavas occupy valleys developed after the elevation of the Eocene surface and, as they were extensively eroded before the Pleistocene, they are assigned to the Miocene.

GLACIATION.

Glaciation is beautifully recorded in numerous cirques about the head and along the south wall of Arrastre Creek canyon. The gulch itself is distinctly U-shaped down to a few hundred yards below Myers Cove mill, where the knob and kettle topography, typical of a terminal moraine, extends in a broad belt across the valley and up its sides for more than 100 feet above the present stream bed. Below this moraine, which is about 6,300 feet above sea level, the valley is distinctly V-shaped. Glaciers probably covered most of the district, moving westward down Silver Creek and merging northeastward with the comparatively large ice sheet which occupied Prairie Basin (p. 40).

ORE DEPOSITS.

Within the district mining operations have been mostly confined to small areas immediately adjacent to Myers Cove and Rabbitfoot. At one time an excitement was started by the finding of opals on Panther Creek, east of Rabbitfoot, as linings and fillings in the vesicles of dark-gray glossy rhyolite, but they did not prove to be present in commercial quantities.

All the deposits known in the district are inclosed in rhyolite. The veins at Myers Cove strike N. 35°–40° E. and dip steeply northwest, but at Rabbitfoot distinct veins have not been recognized. The general crustification of the quartz is perhaps the most conspicuous feature of the deposits. In general the wavy bands parallel the walls, but in detail they are in many places concentrically arranged, either about included fragments of wall rock or as linings in partly filled cavities. In the richer parts of the veins thin, crimped layers of dark

color and dull to submetallic luster occur parallel to the crustification. The quartz, where unaltered, is hard and flinty but instead of having the usual vitreous luster tends to a dull white. On exposure it weathers to a sugary mass with more or less clay intermixed. In the main, however, it is more resistant than the inclosing rhyolite and stands in slight relief.

The following discussion of the ores is of necessity based almost entirely on the Myers Cove ore deposits, although it probably applies closely to all deposits of the district that are inclosed in rhyolite. The ores mined are exclusively gold-silver. Assays have been secured from the Monument mine at Myers Cove which ran several hundred dollars per ton, but on a broad tonnage basis the average is said to be about \$11. The vein material examined microscopically presents many interesting features. The quartz is generally fine grained and occurs in bands composed of grains of slightly different size. Adularia, commonly occurring in beautiful rhombic crystals, is intergrown with the quartz or included in it (Pl. IX, A, p. 54). Pyrite occurs erratically as fine-grained fillings between quartz grains and as small isolated cubes either included in the quartz or intergrown with it. Traversing the general banding of the ore are scattered quartz veinlets a fraction of a millimeter in width, which inclose rarely a cube of pyrite. Adularia was not noted in them.

Gold and silver are said to be present in the ores of the Monument vein at Myers Cove in the ratio by ounces of about 1 of gold to 18 of silver. The form in which they occur is not known, although the presence of much extremely fine-grained pyrite suggests that they may be associated with that mineral. Partial analysis of the ore by W. T. Schaller in the Survey laboratory definitely established a strong trace of selenium. It is thus possible that part of the gold and silver may be in the form of a selenide. (See also pp. 55-56.)

The veins are obviously younger than the inclosing rhyolite, which from its topographic relation is middle or late Tertiary (p. 173). They cut across the valleys and higher reaches of the present rhyolite areas and hence antedate the valleys, which, as they are glaciated, were evidently formed in preglacial time. It follows that the veins are of late Miocene or early Pliocene age.

Concerning the genesis of the ores, the hasty visit necessitates recourse to analogous conditions in well-known districts. From their similarity to deposits which have been studied in detail, these ores are thought to have been deposited by hot ascending waters and are probably to be assigned to the later stages of the igneous activity which gave rise to the extensive rhyolite flows. As shown at Rabbitfoot they are later than the second period of rhyolitic extrusion. For a list of similar deposits see page 57.

MINES.

MONUMENT MINE.

The Monument mine, the principal property at Myers Cove, consists of six patented claims situated on Arrastre Creek near its junction with Silver Creek. It is 6 miles west of Rabbitfoot and 12 miles southwest of Forney. An arrastre was operated on the creek about 40 years ago, but not until the mine was acquired by the present owners in 1896 did active development begin. A. A. Hibbs, Harrisburg, Pa., is general manager. Soon thereafter a considerable amount of ore, averaging about \$11 a ton, was blocked out and the method of treatment carefully considered. As a result a combination chlorination and cyanidation process was adopted. A mill was built but, owing to very low recovery, was operated for only a month or six weeks.

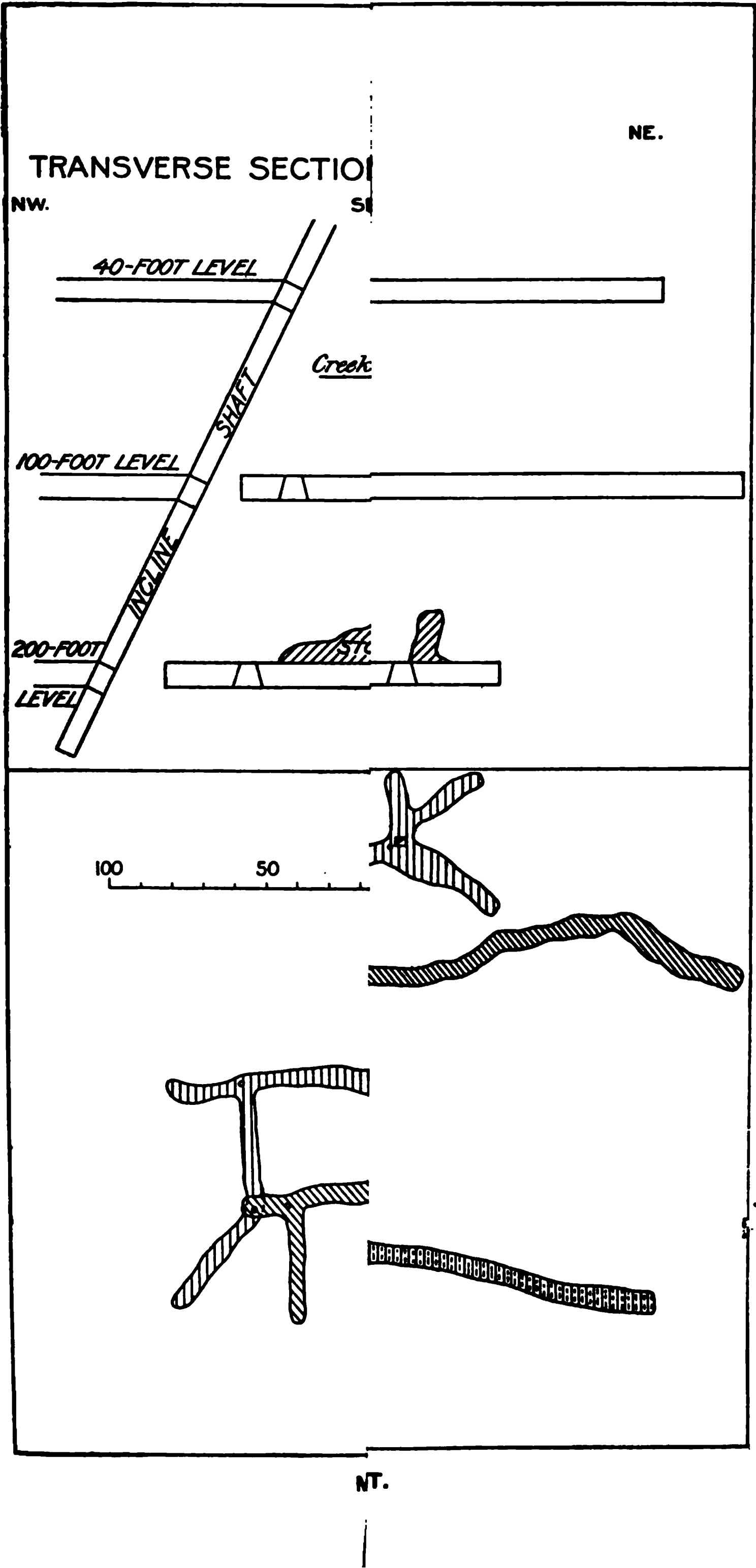
Several small tunnels and shallow shafts have been opened on the property, but the principal development consists of a double compartment incline shaft, which extends down the dip of the vein and from which drifts have been opened on the 40-foot, 100-foot, and 200-foot levels, comprising in all perhaps 3,000 feet of work. (See Pl. XXIII.)

The vein, as seen at the surface and on the tunnel level (the deeper workings being flooded at the time of visit), is a strong quartz lode striking N. 35°–40° E. and dipping 65° NW. It occurs along a brecciated but sharply defined fissured zone about 40 feet wide. The greatest mineralization has taken place along the hanging wall, where 3 to 8 feet of almost clean quartz is usually present. The contact of this with the hanging wall is fairly sharp but with the foot wall it is gradational, stringers of quartz, invariably with sharp contacts, becoming less and less numerous. From the mine map it seems that two parallel veins are present, although but one, locally paralleled by strong stringers, was noted at the surface.

Extensive crushing and weathering have commonly transformed the normal vein filling into a sugary and somewhat clayey mass. Where unaltered the quartz is crustified and in places shows a fine ribbon structure due to dark, crimped bands of dull to submetallic luster. Cavities, few of them more than an inch in diameter, and generally lined with drusy quartz, are common. Pyrite, nowhere abundant and occurring only in very small crystals, is the single mineral seen in the hand specimen. When microscopically examined, however, the ore appears much more interesting (p. 55).

RABBITFOOT (RAME) MINE.

The Rabbitfoot mine is situated in the eastern part of the Gravel Range mining district. It is 6 miles east of Myers Cove and 9 miles south of Forney. Although located in 1872, active exploitation of



11

GEOLOGY.

Algonkian sedimentary rocks are exposed only in the deeper gulches, most of the surface rocks being late Tertiary eruptives—rhyolites, tuffs, and a few trachytes. The rhyolites are predominantly dark gray to steel-gray in color and are made up of phenocrysts of quartz and less orthoclase sparsely set in a glassy to fine-grained groundmass. The tuffs, although widely distributed, are most conspicuously exposed just west of Twin Peaks, where they are upwards of 300 feet thick, and consist of roughly stratified beds of chalky-white color. Included in them are a few fragments of quartzite, schist, and rhyolite, but the main mass is an aggregation of pumice and angular fragments of quartz, orthoclase, and glass. Overlying them in the south peak is a band of rhyolite, possibly 500 feet thick. Trachyte, similar to the rhyolite but without quartz and generally presenting a rougher surface or fresh fracture, is known to be present as thin bands between some of the rhyolite flows. Its relative importance was not determined.

ORE DEPOSITS.

The short time available for looking over the deposits—only a few hours—necessitated a very cursory examination. That they are, however, of the same general type as those of the Gravel Range district is perfectly clear. The veins, which vary in width from stringers up to 3 or 4 feet, strike N. 20° E. and dip 55° NW. They are fissure fillings with many angular fragments of wall rock included. Lateral spurs leading out along joint and fracture planes are abundant, and in places narrow bands of quartz lie parallel to the main vein, either in the hanging or foot wall. Broadly, the vein quartz is crustified parallel to the inclosing walls, but in detail it is in many places concentrically arranged.

The quartz is fine grained. When examined in thin section, it is seen that the crustified appearance is due to alternating layers of different coarseness. Intermixed with the quartz are many small fibers and flecks of sericite, but whether these are primary or are derived from the breaking down of the adularia known to be present could not be determined from the extremely altered ore which alone was available. A very fine-grained metallic mineral of bluish-white color occurs in blotches and isolated specks. It was not identified. The ore contains gold and silver in proportions which vary markedly from place to place, although everywhere more valuable for gold. Common assay values are said to be \$12 to \$20 a ton.

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J. C. Branner

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

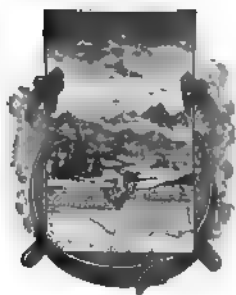
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 529

THE
ENRICHMENT OF SULPHIDE ORES

BY

WILLIAM HARVEY EMMONS



WASHINGTON
GOVERNMENT PRINTING OFFICE
1913



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THE ENRICHMENT OF SULPHIDE ORES.

By WILLIAM HARVEY EMMONS.

INTRODUCTION.

STATEMENT OF THEORY.

Sulphide ores exposed to weathering at or near the surface of the earth break down and form soluble salts and minerals that are stable under surface conditions. No metallic sulphide that is long exposed to air and water remains unaltered. Iron sulphides, which are present in practically all sulphide ores, are changed by weathering to iron oxides, and the changes are attended by the liberation of sulphuric acid. Many of the metals form soluble sulphates with sulphuric acid, and when conditions favor their migration downward they are carried in solution to depths where air is excluded. Unoxidized rocks are in general alkaline. Acid solutions that encounter such rocks in the regions where air is excluded will lose acidity, and as the solutions approach a neutral or alkaline condition some of the metals they contain are deposited. If the solutions of the metallic sulphates encounter metallic sulphides in depth precipitation may take place, or there may be an interchange between the metals in solution as sulphates and the metallic sulphides. Thus as a result of precipitation or chemical interchange the metals are redeposited and certain portions of the ore bodies become enriched.

The theory of sulphide enrichment, announced in 1900, has been found to have wide application. Many deposits, especially of ores of copper, are leached near the surface and are richer below the leached zones. The ore at still greater depths is of lower grade. According to the theory the copper leached from the upper zone has been carried downward and redeposited, forming an enriched zone, and the deeper, lower-grade sulphide ores are assumed to be like the original or primary mineralization of the whole deposit. Some deposits of gold ores and of silver ores show similar features, but the changes in the character of the ore in such deposits are generally less notable. Relatively few deposits of lead and zinc have clearly defined secondary sulphide zones, although some such deposits show appreciable enrichment. The theory of sulphide enrichment has now become fairly well understood and has proved to be of considerable economic value, for it has been successfully applied in the development of many deposits of the metallic sulphides.

Similar geologic processes operating under approximately similar conditions produce approximately similar results, and any theory formed to explain the relations that exist in some deposits might reasonably be cited to explain the absence of like relations in other deposits. It has been found, however, that the theory of sulphide enrichment does not apply to all deposits and that many valuable deposits of sulphide ores are primary. It is not applicable even to all deposits of copper-bearing sulphides, in which secondary changes that have taken place are recorded more clearly than in deposits of other metals. Moreover, it is not clear why some deposits show extensive enrichment and others show little or none.

As data are accumulated some of the geologist's most cherished hypotheses may be overthrown. Until recently nothing seemed to rest on a firmer foundation than the belief that the presence of chalcocite is almost certain evidence of enrichment by cold solutions, but recent studies have shown that, without much doubt, this mineral is a primary constituent of certain copper ores that have been deposited by ascending thermal waters.

The recent development at Bisbee, Ariz. (p. 182), of extensive and deep oxidized ores related to a pre-Comanche erosion surface which is not parallel to but is inclined to the present underground water level; the development at Miami, Ariz. (p. 185), of an extensive chalcocite zone not definitely related to but apparently older than the present topography; and the exceptional features of the secondary deposits in several other districts clearly indicate that the theory of sulphide enrichment can not be applied perfunctorily to any deposit. The deductions that may be drawn from it are generally of so great commercial importance that its use is fraught with danger unless it is used with an adequate understanding of the general geology of the region containing the deposits to which it is applied.

The chemistry of sulphide enrichment offers an especially attractive field for experimental study because the natural conditions of temperature, pressure, and concentration can be closely duplicated in the laboratory, but at present the results of chemical experiments in ore enrichment leave much to be desired. It should be acknowledged at the outset that some of the data concerning sulphide enrichment appear to be conflicting and that many of the problems are now only in process of solution.

This paper is offered not as a contribution of many original data, but rather as a summary of a part of the existing knowledge of the subject. I hope it may suggest to those who are engaged in geologic work and in mining some lines of approach to the problems to be solved. The solution of these problems must depend very largely on the observations of the engineer or geologist who can watch the

changes in the successively excavated parts of an ore body. He has a distinct advantage over the official geologist, who visits it only at one stage of its development, perhaps after the most illuminating exposures have been destroyed. To the chemist this paper is an appeal for more experimental data on the important mineral syntheses involved in the processes. I realize fully that there may be serious omissions and possibly serious errors in the discussion of the complex and scattered data here presented, and I shall esteem it a favor if anyone whose statements I may have misquoted or misinterpreted will set me right, and if those who have had superior opportunities for study of certain districts will correct any wrong impressions that I may have given.

SOURCES OF INFORMATION AND ACKNOWLEDGMENTS.

Among the papers that treat the subject of sulphide enrichment are those of S. F. Emmons,¹ W. H. Weed,² and C. R. Van Hise.³ These papers were issued in 1900, almost contemporaneously, and in them the writers, working independently, assembled the geologic and chemical data bearing on the problem, formulating a clearly stated theory from scattered and undigested observations. Five years later Kemp⁴ wrote a summary of the processes of secondary enrichment of ore deposits of copper, and in 1910 Ransome⁵ issued a comprehensive review of the criteria of downward sulphide enrichment, in which he treats concisely the various processes of enrichment and their results. The nearly related processes of oxidation of ore deposits were discussed by Penrose in 1894.⁶

During the 12 years that have passed since the first papers on sulphide enrichment were issued a number of detailed reports have appeared, treating the geology and ore deposits of certain mining districts. In several of these papers the chemical processes involved are discussed in the light of the field relations of the deposits. The contributions of Lindgren, Ransome, Spencer, Boutwell, Irving, Graton, Spurr, Garrey, Ball, Butler, Lawson, and Gordon are particularly valuable. Since 1905, when the work of collecting the mineral statistics of the United States was placed in the hands of field geologists, the annual reviews of resources, production, and development that have appeared in the reports entitled "Mineral

¹ Emmons, S. F., The secondary enrichment of ore deposits: *Trans. Am. Inst. Min. Eng.*, vol. 30, 1901, pp. 177-217.

² Weed, W. H., The enrichment of gold and silver veins: *Trans. Am. Inst. Min. Eng.*, vol. 30, 1901, pp. 424-448.

³ Van Hise, C. R., Some principles controlling the deposition of ores: *Trans. Am. Inst. Min. Eng.*, vol. 30, 1901, pp. 27-177.

⁴ Kemp, J. F., Secondary enrichment in ore deposits of copper: *Econ. Geology*, vol. 1, 1906, pp. 11-25.

⁵ Ransome, F. L., Criteria of downward sulphide enrichment: *Econ. Geology*, vol. 5, 1910, p. 205.

⁶ Penrose, R. A. F., jr., The superficial alteration of ore deposits: *Jour. Geology*, vol. 2, 1894, p. 288.

resources of the United States" have been a never-failing source of information. The chapters on gold, by Waldemar Lindgren and H. D. McCaskey; those on copper, by L. C. Graton and B. S. Butler; those on lead and zinc, by C. E. Siebenthal; and those on the rarer metals, by F. L. Hess, have furnished many valuable data.

Data on the chemistry of the processes of sulphide enrichment have been accumulated rapidly since 1900. The paper by Schuermann¹ published in 1888 was for many years the most important source of information respecting the behavior of sulphides in certain reactions involving double decomposition. In 1907 Weigel² published a paper showing the solubilities in water of the metallic sulphides, which, as was pointed out by R. C. Wells,³ correspond closely in order to the series found by Schuermann. In 1903 H. V. Winchell⁴ published the results of experiments in chalcocitization of sulphide ores. More recently experiments in the solution or precipitation of the metals have been made by Sullivan, Wells, Allen, Stokes, Buehler and Gottschalk, Brokaw, Cooke, Grout, A. N. Winchell, and many others.

I wish to acknowledge my indebtedness to my colleagues of the United States Geological Survey, especially to Messrs. Waldemar Lindgren, F. L. Ransome, A. C. Spencer, and B. S. Butler, who have read portions of this paper and have generously contributed unpublished data on certain districts. Mr. R. C. Wells, of the United States Geological Survey, and Dr. W. H. Hunter, of the University of Minnesota, have read critically certain parts of this paper, where the problems of physical chemistry are treated, and many of the reactions have been discussed with Dr. E. T. Allen and associates, of the Carnegie geophysical laboratory at Washington, and with Mr. F. W. Clarke of the United States Geological Survey.

DISTINCTIONS BETWEEN PRIMARY AND SECONDARY DEPOSITS.

In this paper I apply the term primary to all bodies of ores whose chemical and mineral composition have remained essentially unchanged by superficial agencies since the ores were deposited. These include sulphide ores that have replaced the wall rock and are "secondary" after rock-making minerals or sedimentary beds. A secondary ore, as the term is here used, is one that has been altered by superficial agencies. The term is not restricted to pseudomorphous replacements but is used to include also material deposited by super-

¹ Schuermann, Ernst, Ueber die Verwandtschaft der Schwermetalle zum Schwefel: *Liebig's Ann. der Chemie*, vol. 249, 1888, p. 326.

² Weigel, Oskar, Die Löslichkeit von Schwermetallsulfiden in reinem Wasser: *Zeitschr. phys. Chemie*, vol. 58, 1907, pp. 293-300.

³ Wells, R. C., The fractional precipitation of sulphides: *Econ. Geology*, vol. 5, 1910, pp. 1-14.

⁴ Winchell, H. V., Synthesis of chalcocite and its genesis at Butte, Mont.: *Bull. Geol. Soc. America*, vol. 14, 1903, pp. 269-276.

ficial processes in fractures in and near the primary ore bodies. It is unfortunate that the term "secondary" is used with different meanings and that the distinction between primary and secondary ores can not everywhere be sharply drawn, but the diverse usage of the terms has become firmly fixed in the literature, and ambiguity can generally be avoided only by using qualifying phrases.

A discussion of the genesis of primary ore deposits does not come within the scope of this review, but in order to distinguish clearly between primary and secondary ores as the terms are here used, it is desirable to mention briefly the several classes of primary deposits. Any attempt to classify ore deposits by means of the data now available is hazardous. Sharp divisions are not generally found in nature, and any classification based on genesis should be regarded merely as a convenient means of comparison and study. Not only do some classes of primary ores overlap one another, but primary ores formed at moderate depths by cold solutions and those formed very near the surface by ascending thermal waters are in many respects similar to deposits formed by descending sulphate solutions in processes of secondary alteration, and it is not everywhere practicable to draw sharp distinctions between them. The following classification includes the more important groups of primary ores:

Syngenetic deposits; contemporaneous with the inclosing rocks:

Sedimentary beds; mechanical, chemical, organic, etc.

Magmatic segregations; consolidated from molten magmas.

Epigenetic deposits; deposited later than the inclosing rocks:

Pegmatite veins; deposited by "aqueo-igneous" magmatic solutions.

Contact-metamorphic deposits; deposited in intruded rocks by fluids passing from consolidating intruding rocks.

Deposits of the deep vein zone; formed at high temperature and under great pressure, generally in and along fissures.

Deposits formed at moderate and shallow depths by ascending hot solutions.

Deposits formed at and near the surface by ascending hot solutions.

Deposits formed at moderate and shallow depths by cold meteoric solutions.

The deposits of any of these groups may be changed by various geologic processes. They may be buried deeply and altered by dynamic metamorphism, or, if exposed to surface agencies, they may be leached or enriched by superficial processes.

Sedimentary beds are the sources of a great many economic products—such as coal, clay, oil, iron ore, or manganese. Of the sulphide ores, however, very few are sedimentary. Some of the copper deposits in the "Red Beds" have been considered sedimentary. The best known example is the "Kupferschiefer" of Mansfield, Germany. Workable sulphide deposits of sedimentary origin in the United States are unknown to me.

Magmatic segregations are products of the differentiation of igneous magmas. Genetically considered they are in the strict sense igneous

rocks. These deposits include ore bodies of considerable economic importance, among them some of the magnetic iron ores of the Adirondack Mountains, in New York. No large sulphide deposits of this kind are known in the United States. The nickel-copper deposits of Sudbury, Ontario, are the best-known examples of this group in North America. These deposits have been planed off by glacial erosion in recent geologic time and do not show any considerable enrichment by superficial processes.

Pegmatite veins are very nearly related to magmatic segregations. They are magmatic segregations or end products of crystallization that have been thrust, like igneous dikes, into openings in rocks already consolidated. As they are probably formed from eutectic solutions, many pegmatite veins tend to approach a fairly uniform composition and are also generally characterized by large crystals of rock-making minerals. Pegmatites that have not moved from the parent magma and are not related to openings in rocks could properly be classed with syngenetic deposits, as magmatic segregations, but some authorities reserve the latter term for the more basic differentiation products. In pegmatites the sulphides are present, as a rule, in small quantities, and except some deposits of rare elements they have very little economic importance as sources of the metals.

Contact-metamorphic deposits are formed in intruded rocks by fluids given off by intruding igneous magmas. Many of the ores of such deposits contain the sulphides of copper, zinc, and lead, intergrown with heavy silicates and calcite. In general the ore bodies of this class are not clearly related to determinable fissures. Many of these deposits have been enriched by superficial alteration. As a rule the changes are easily followed in the field, for many minerals that are formed by contact-metamorphic processes are not formed by processes of superficial alteration, and vice versa. In general sulphide enrichment does not extend to great depths in contact-metamorphic ores; the tough, fibrous, or platy minerals of the gangue do not favor extensive fracturing, and the presence of calcite favors precipitation of secondary carbonates near the surface. Noteworthy exceptions to this rule are known.

The deposits of the deep vein zone are mineralogically related, more or less closely, to contact-metamorphic deposits. They have formed in and along openings in rocks, however, and in the main they approach the tabular form more closely than do the contact-metamorphic deposits. As pointed out by Lindgren, who first defined the group, the deposits of the deeper zone have formed under conditions of high temperature and pressure, which prevail also in contact metamorphism. Because high temperature and pressure are necessary for their genesis these deposits do not form at moderate or shallow depths, at least not in fissures that extend to the surface, and there-

fore they are seldom found in the more recent rocks. The deposits of this group are closely affiliated with the contact-metamorphic deposits on the one hand and with deposits formed at moderate depth on the other and can not be sharply divided from the latter. If this class is made to include only deposits that are related to openings in rocks and that carry in the gangue some of the contact-metamorphic minerals (such as heavy silicates, magnetite, or specularite), it may be said that the examples found in the United States are but little affected by sulphide enrichment. The gold deposits of this group are generally not manganiferous, and silver is not an important constituent of most of them. On the other hand, some important sulphide deposits of copper that carry pyrrhotite and magnetite might be included in this group, and sulphide enrichment has played an important part in the genesis of a number of these pyrrhotitic copper deposits.

The deposits formed at moderate and shallow depths by ascending thermal solutions constitute a very important group, which includes numerous deposits of ores of copper, gold, silver, lead, and zinc. Many of these deposits show important sulphide enrichment and illustrate the downward migration of the metals. Some of them are noted for relatively small bodies of very rich ore, locally developed in a larger lower-grade deposit. This group, more than any other, may be characterized as the "bonanza" group. Some of the bonanzas are due to sulphide enrichment, but doubtless many of them are primary.

Much may be said for the theory that some of the metals are precipitated most effectively from ascending thermal alkaline solutions in the zone where they first encounter descending ground water. Whether the solutions are alkali chlorides, alkali sulphides, or alkali carbonates, a decrease in temperature and partial oxidation would cause precipitation. An alkali sulphide solution containing iron would be converted to a ferrous sulphate solution, and from such a solution gold would be deposited almost completely. Some of the metals may be precipitated from alkali sulphide solutions merely by dilution. In the deposits of this group, more than in any other, the presence of bonanza ore has little genetic significance. Each deposit and each ore shoot is a separate problem. Even its relation to the present surface is not everywhere conclusive, for obviously the primary bonanzas may have a genetic relation to a former zone of ground water—a zone which is itself superficial but which may not be determinable.

Deposits of sulphide ores formed at or very near the surface by ascending hot solutions are mainly of scientific rather than economic importance, although a few of them have been exploited for the metals. As atmospheric oxygen is present in the superficial zone the minerals they contain include the hydrous oxides and various sulphates, and as the pressure is nearly atmospheric the temperature

can not be much above 100° C. Consequently the minerals form under physical conditions that are not greatly different from those found in the zones of surface alteration and sulphide enrichment where ores are exposed to the action of surface agencies.

The deposits formed at moderate and shallow depths by cold solutions include a large number of important deposits of lead and zinc in the Mississippi Valley and many copper deposits in Colorado, New Mexico, and Utah. Examples could be multiplied, but these define the type. The conditions under which these deposits form are doubtless closely similar to those which exist in zones of sulphide enrichment, and many of the minerals formed are found also in the secondary sulphide zones. Much evidence has been cited to show that these deposits were formed by ground water that gathered its metallic contents from great masses of rocks in which the metals were sparingly disseminated. The metallic salts, chiefly sulphates and chlorides, were gathered in water channels, and the metals were deposited as sulphides where conditions were favorable. In many examples some form of organic material supplied the precipitating agent. If deposition had taken place on an older sulphide these deposits would be classed as secondary sulphide ores, but in general there is no evidence that bodies of older sulphide ore occupied the place of the deposits. These ores are therefore considered primary, although they have been leached by ground water from an older metalliferous rock.

PHYSICAL CONDITIONS AND ENRICHMENT.

The processes of sulphide enrichment depend on the physical conditions, the environment, and the geologic history of the deposits and on their chemical and mineral composition. Of the purely physical conditions, the climate, altitude, and relief are important. Permeability of the deposits is an essential condition, for if solutions can not find access to the lower horizons the metals dissolved near the surface may be scattered. The duration of the period of weathering is important also, for under similar conditions the amount of solution is directly proportional to the time during which the deposits are exposed to weathering. Briefly, there is scarcely a feature of the geologic history of a deposit that may not affect the extent and character of its enrichment.

CLIMATE.

TEMPERATURE.

A warm climate, in so far as it favors chemical action, is favorable to sulphide enrichment. Deposits in high latitudes are not so likely to show extensive migration of the metals, because low temperature decreases chemical activity, and freezing prevents solution. Where the ground is frozen to considerable depths during the winter

and thaws out only a short distance below the surface during the summer, thorough weathering can not extend to great depths. Assuming the persistence of the present relation between latitude and climate, it may be said that bonanzas of secondary ore are probably less numerous and less extensive in higher than in lower latitudes.¹

In late geologic time large areas in northern latitude have been glaciated, and in many places the surface has been planed off by ice erosion. The altered zones of many deposits have doubtless been removed. Thus the deposits of the North differ from those of lower latitudes in two essential respects—in environment and in geologic history. To what extent the smaller development of secondary sulphide ores in the North depends on present temperature and other climatic conditions, and to what extent it is due to recent glacial action, are questions that probably will not be answered until more data are available concerning deposits in driftless areas in high latitudes. In Alaska, Canada, and New England there are but few sulphide deposits of proved secondary origin that are comparable in extent or value to those which have formed at lower latitudes. The available evidence indicates that the large and important ore bodies of these countries are mainly of primary origin. The gold deposits of Douglas Island, Alaska, the copper deposits of Kasaan Peninsula, Latouche Island, and Prince William Sound, and the nickel and copper deposits of the Sudbury region are not deeply oxidized. Carbonate ores extend to a depth of 300 feet in the Copper Mountain mines, Prince of Wales Island, and chalcocite and native copper lie at least 200 feet deep at the Goodro mine.² In many of the deposits in the North, however, the ore has proved to be of approximately uniform grade to considerable depths.

On the other hand, it is well known that great climatic changes have taken place in many regions, and that temperatures have been by no means constant throughout geologic time. Therefore, because the processes of weathering of ore bodies are slow to-day in certain places, it does not follow that they have always been inactive there, and under some conditions secondary deposits formed in older geologic periods in places protected from erosion should be preserved to-day.

The famous Bonanza mine of the Chitina copper belt, Alaska, described by Moffit and Maddren,³ presents some unusual features,

¹ Winchell, H. V., *Prospecting in the North*: Min. Mag., vol. 3, 1910, pp. 436-438. Brock, R. W., *Discussion of H. V. Winchell's article "Prospecting in the North:"* Min. Mag., vol. 4, 1911, pp. 204-206.

² Wright, F. E. and C. W., *The Ketchikan and Wrangell mining districts, Alaska*: Bull. U. S. Geol. Survey No. 347, 1908. Wright C. W., *Discussion of H. V. Winchell's article "Prospecting in the North:"* Min. Mag., vol. 4, 1911, p. 359.

³ Moffit, F. H., and Maddren, A. G., *Mineral resources of the Kotsina-Chitina region, Alaska*: Bull. U. S. Geol. Survey No. 374, 1909, pp. 80-86.

which should be mentioned here. The principal deposit is a great mass of chalcocite and bornite, the ore carrying considerable silver and occupying a fractured zone in limestone. There is no evidence that the ore has replaced older sulphides. Although Moffit and Madren do not state definite conclusions as to the origin of the ore, their discussion clearly implies a genesis independent of magmatic waters. No other conclusion seems to be warranted by the facts available. Geologic and physiographic studies appear to indicate that the Bonanza ore deposit was formed at considerable depth by meteoric waters, which implies that at some period processes of solution and precipitation have operated vigorously in this high latitude.

The rich native silver ores of Cobalt, Ontario, have been considered secondary by some geologists, but all who have studied these deposits are not agreed as to their genesis.¹ Doubtless some enrichment has taken place in the Copper Cliff and Vermilion mines of the Sudbury region, Ontario. In the Vermilion mine, according to Barlow, native copper, probably derived by alteration from chalcopyrite, is found 900 feet below the surface.² In general, the secondary sulphide zones of deposits in western Canada in about the same latitude as these are not extensive, but some deposits—for example, the St. Eugene mine, in British Columbia—show unmistakable evidence of sulphide enrichment. The developments in southwestern Canada are not sufficient to permit conclusive statements. There is doubtless a relation between latitude and sulphide enrichment, but it is one which can not be expressed as an invariable rule.

On the other hand, many sulphide deposits in lower latitudes do not show sulphide enrichment. Examples are mines lying in the foothill copper belt, California (see p. 202); La Reforma mine, Mexico (p. 211); the Copper Queen mine, Velardeña, Mexico (p. 211); and several deposits of the Braden Copper Co., Chile (p. 203). According to J. M. Moubray,³ several deposits in the Kafue copper district, in northern Rhodesia, between 13° and 14° south of the Equator, show copper sulphides at the very surface. In the Sable Antelope mine of this region superficial alteration is practically absent.

RAINFALL.

Since water is the agent of ore enrichment, abundant rainfall is favorable to the formation of secondary ores. The activity of ground water depends principally, however, on the natural acids and other compounds which it dissolves, and the waters in regions of oxida-

¹ Miller, W. G., Notes on the cobalt area: Eng. and Min. Jour., vol. 92, 1911, pp. 645-649. Emmons, S. F., Types of ore deposits, San Francisco, 1911, p. 140.

² Barlow, A. E., The nickel and copper deposits of Sudbury, Ontario: Ann. Rept. Geol. Survey Canada vol. 14, pt. H, 1904, p. 106.

³ Moubray, J. M., Discussion of H. V. Winchell's article, "Prospecting in the North:" Min. Mag., vol. 4 1911, pp. 117-118.

tion and solution are generally not saturated with acids. Thus, even in arid regions a moderate supply of ground water under conditions favorable to permeability may bring about appreciable results in relatively brief geologic periods. Some of the silver-gold deposits of the Great Basin clearly show sulphide enrichment, although the primary ores were deposited as late as or later than the Miocene epoch. Ores that form some of the best examples of sulphide enrichment seen in the United States are found in early Tertiary deposits that occur in the arid Southwest, where the annual rainfall is not more than 10 or 12 inches. In some of these deposits, however, much of the secondary ore was probably formed when the rainfall was greater. Concerning this point it is obviously difficult to draw any general conclusions, because data regarding the former climates of many arid regions are inadequate.

In arid countries the ground-water level is likely to lie deep, and the zone of solution is generally not clearly differentiated from the zone of precipitation. Above the water level in ore deposits in arid regions there may be considerable amounts of primary sulphide ore, of secondary sulphide ore, and of oxidized ore, all at approximately the same horizon. In such deposits the secondary sulphide ores, though occurring through greater vertical ranges, may not be concentrated in small volume.

ALTITUDE.

As a rule, the relief is great in areas of high altitudes, and erosion is consequently more rapid. Moreover, in such areas temperatures are lower and conditions are less favorable to solution. Deposits located at very high altitudes, where rocks are disintegrated by frost and carried away unweathered as talus and boulders, are not so likely to be extensively enriched as are deposits that lie at lower altitudes. On the other hand, the processes of enrichment are effective under some conditions at considerable altitudes. Many deposits in Colorado that outcrop at altitudes over 10,000 feet above sea level and some in Montana that outcrop at about 8,000 feet above sea level contain extensive zones of secondary ores.

RELIEF.

In so far as strong relief supplies head, it is favorable to deep and rapid circulation of underground water, and it is likewise favorable to relatively deep enrichment. In base-leveled regions underground circulation is sluggish and the nearly stagnant waters can not descend far into the zone of primary sulphides without losing the valuable metals which they dissolve higher up. Calculations made for lodes in the base-leveled region that includes Ducktown, Tenn., show that all or nearly all of the secondary copper in the chalcocite zones may

is indicated by the fact that the leaching of the mass below the surface is not uniform. That the conditions which prevailed in the region of the deposit are such that a large part of the copper is deposited in the form of a secondary sulphide zone that was formed after the primary zone had been deposited has been indicated by the fact that the primary zone was deposited in the form of a secondary sulphide zone and in those cases that the primary zone was deposited in the form of a secondary sulphide zone the conditions would have been such that the primary zone would have been deposited in the form of a secondary sulphide zone. The available data regarding the deposition of secondary sulphide ores is such that for nearly all ore deposits the conditions of deposition are in areas of moderate to high pressure.

DEPOSITION

Deposition is essential for sulphide enrichment. If the primary zone is not formed in the conditions that exist downward through the primary zone will not be formed along the contact between the primary and secondary zones and ultimately will escape into fractures in the wall rock or escape in some level below the points of contact. If there is no enrichment in the primary zone the metals may be scattered. In rocks that have been shattered by strong movements since the primary ore was deposited there is generally more extensive and better enrichment than in deposits that have been shattered by fracturing. Brittle minerals like quartz and chert fracture and shatter and are composed largely of the brittle minerals and are more easily shattered than deposits of tough or elastic minerals. Many of the best secondary sulphide ores of contact metamorphism are in the form of a large fragment of volcanic rocks amphibole, mica, and other minerals in the form of secondary enrichment to the primary.

In a great many deposits especially in the western part of the United States pronounced earth movements have occurred since the ore was formed. Many deposits all fissures or were formed in zones of fracturing that are planes of weakness along which movements took place before the deposition. To relieve subsequent stresses the same zones of fracture may be again fractured, like a rod that breaks and is welded. Such later fracturing has taken place in many mineral deposits after the primary ore was deposited and consequently many of the planes of later movement may parallel the veins, following one wall or the other or cutting irregularly across the ore. If the deposit is composed of material that is easily fractured, such as quartz or chert, the ore may become brecciated and may therefore contain many small openings. A large number of small openings, such as may result from fracturing or shattering of

the primary sulphides, are more favorable to concentrated enrichment than a few larger openings, for a larger surface of primary ore is exposed to solution along many small openings than along a few large openings. Moreover, inasmuch as friction is greater along small openings, the descent of solutions in them is retarded and therefore reactions that result in precipitation of secondary sulphides may be brought nearly to completion at relatively shallow depths. Very small openings, such as the pore spaces of minerals and other capillary or subcapillary openings, are not effective water channels because friction along them retards circulation. Under some conditions, however, mineral-bearing solutions do penetrate these minute openings and deposit ore in them. In certain deposits near Globe, Ariz., according to Ransome,¹ specks of secondary chalcocite ore are embedded in solid veinlets of quartz and in silicified schist, indicating a migration of copper, for short distances at least, through exceedingly minute openings. Although water may penetrate such minute openings, it does not circulate freely in them but is nearly stagnant. It would be supposed that the metals would not be carried far in such openings before precipitation, at least not in rocks that are readily attacked by the solutions, but if the openings are lined with siliceous alkali-free minerals or with other minerals that are but slowly affected by the solutions, the reactions which reduce and tend to neutralize the solutions and to precipitate the metals would take place more slowly and the metals might be carried in solution to greater depths.

INFLUENCE OF RATE OF EROSION ON RATE OF SULPHIDE ENRICHMENT.

In so far as strong relief is favorable to rapid erosion it is unfavorable to thorough leaching. Where erosion is slow the outcrops and upper portions of deposits are exposed to processes of weathering for periods long enough to favor thorough leaching and, if the metals are reprecipitated at lower depths, to favor ore enrichment. On the other hand, erosion may be delayed to a point beyond which it is unfavorable to solution and precipitation. The downward migration of the zone of oxidation exposes new surfaces to solution, making masses of fresh sulphides available for reconcentration. Consequently where metals dissolve readily, comparatively rapid erosion may favor rapid concentration. The metallic contents of many deposits of secondary ores represent not only what has been leached from the gossan now exposed but also what has been dissolved from portions of the deposits that have been carried away by erosion.

¹ Ransome, F. L., Criteria of downward sulphide enrichment: *Econ. Geology*, vol. 5, 1910, pp. 217-218.

AGE OF THE PRIMARY DEPOSITS AND THEIR PERIODS OF WEATHERING.

Other conditions being similar, the amount of enrichment must depend on the length of time the deposits have been exposed to weathering and erosion. In general, weathering has acted for a shorter time on late Tertiary deposits than on middle Tertiary, early Tertiary, or Cretaceous deposits. The age of the deposit is not, however, invariably the most important factor in determining the extent of its enrichment, for some of the middle or late Tertiary deposits, such as those in the southwestern part of the United States, show more extensive migration of the metals than is shown by some older deposits which have been exposed to weathering for a much longer time.

In the United States the bonanza deposits of the precious metals are in the main the younger ones, for in general the Paleozoic and older deposits are less rich, though many of them are more nearly uniform in value. Many of the middle or late Tertiary deposits of the precious metals in the Great Basin region—such as those of Tonopah,¹ the Comstock lode,² and Tuscarora, Nev.—show unmistakable evidence of enrichment, yet there are good reasons for supposing that the primary ores of many of these young deposits were originally somewhat richer nearer the surface than at greater depths. The deposits of Cripple Creek, Colo.,³ and of Goldfield, Nev.,⁴ show a similar relation as to values and depth, yet sulphide enrichment has probably not been appreciably important in either of these districts. Gold is generally slow of solution, especially where the environment is not favorable to solution. As pointed out by Graton,⁵ some of the gold deposits of the Appalachian region are workable at their outcrops, where gold has remained undissolved ever since the peneplanation of the region, which probably took place as early as Tertiary time.

In general, the sulphide deposits that show the most clearly defined secondary zones are those of copper. The periods of primary deposition of all the known important copper deposits of determined age in the United States, except those of Tintic, Utah, probably antedate the Miocene, and all have long been exposed to erosion and weathering.

¹ Spurr, J. E., *Geology of the Tonopah mining district, Nevada*: Prof. Paper U. S. Geol. Survey No. 42, 1905, p. 95.

² Becker, G. F., *Geology of the Comstock lode and the Washoe district*: Mon. U. S. Geol. Survey, vol. 3, 1882, p. 273.

³ Lindgren, Waldemar, and Ransome, F. L., *Geology and gold deposits of the Cripple Creek district, Colorado*: Prof. Paper U. S. Geol. Survey No. 54, 1906, p. 204 and Chapter XI.

⁴ Ransome, F. L., *Geology and ore deposits of Goldfield, Nev.*: Prof. Paper U. S. Geol. Survey No. 66, 1909, pp. 191-195.

⁵ Graton, L. C., *Reconnaissance of some gold and tin deposits of the southern Appalachians, with notes on the Dahlonega mines by Waldemar Lindgren*: Bull. U. S. Geol. Survey No. 293, 1906, p. 67.

According to Ransome,¹ the deposits at Bisbee, Ariz., may have been exposed to processes of alteration as far back as the Cretaceous. The copper deposits of Velardeña, Mexico, according to Spurr and Garrey,² are probably later than middle Tertiary. The deposits of the Braden mine of Chile, as shown by Pope Yeatman,³ are likewise of comparatively late age. In neither of these districts where Tertiary ores are developed are the secondary sulphide zones conspicuously shown. Many copper deposits of the eastern United States are much older, the more important ones having been formed in Paleozoic or earlier periods. Although some of these deposits have long been exposed to erosion, their secondary sulphide zones, though rich and well defined, are not nearly so deep nor so extensive as some in the younger deposits of the West.

I have found no record of secondary sulphide zones that were unquestionably formed in pre-Mesozoic time, although zones of oxide enrichment as old as the Archean are known. According to Van Hise and Leith 'some of the rich specular hematites of the Vermilion range are the metamorphosed products of surface enrichment that were indurated and infolded before the beginning of Algonkian time.

PALEOPHYSIOGRAPHY.

Inasmuch as sulphide enrichment depends on the action of surface agencies, it is important to know as far as possible the details of the history of any deposit considered, the length of time it has been exposed to weathering, and whether faulting or folding or a second episode of primary ore formation has taken place since it was first formed. In short, any geologic or physiographic data might have a bearing on the problem of enrichment.

If the present topography is like that which prevailed when primary deposition took place—and this may be the case if the deposits were formed in comparatively late geologic time—then the richer ore of the primary deposits may have an obvious relation to the present surface. In some deposits of gold and silver ore the maximum precipitation of the metals appears to have taken place at relatively short distances below the surface that existed at the time of deposition. Thus the primary ore may show a comparatively constant change in value, which may decrease with increasing depth. In general, the more remote the period of primary deposition the less the probability that the important features of the present topography are similar to those which existed when the primary ores were deposited and the less

¹ Ransome, F. L., The geology and ore deposits of the Bisbee quadrangle, Arizona: Prof. Paper U. S. Geol. Survey No. 21, 1904, p. 160. Also this bulletin, p. 179.

² Spurr, J. E., and Garrey, G. H., Ore deposits of the Velardeña district, Mexico: Econ. Geology, vol. 3, 1908, pp. 724-725.

³ Yeatman, Pope, The Braden copper mines: Min. and Sci. Press, vol. 103, 1911, pp. 760-772.

⁴ Van Hise, C. B., and Leith, C. K., The geology of the Lake Superior region: Mon. U. S. Geol. Survey, vol. 52, 1911, p. 142.

the probability of error in attributing the deposition of a rich primary zone to secondary processes.

STRUCTURAL FEATURES AND BLIND LODES.

Lodes that do not outcrop are termed "blind" lodes. Some of them do not outcrop because the primary ores did not extend to the present surface, others have been faulted off near the surface, and still others have been covered by formations deposited later than the ores. A fissure across a sedimentary series may end abruptly just below or at a bed of shale, and the ore that fills it will then be exposed only where the shale has been eroded away. The portion of a lode that is now capped by an impervious shale will not have been enriched by oxygenated waters unless, because of certain structural conditions, such waters were conducted laterally below the shale bed to the lode. Such structures as thin saddle reefs, thin anticlines, and thin flat-lying beds are not particularly favorable to extensive sulphide enrichment, because they may be eroded in comparatively short time and because the conditions below the deposits they contain are not likely to be so favorable to precipitation as they are in deposits or in parts of deposits that are underlain by sulphide ores. In the absence of material below that may react with the solutions and readily cause precipitation, the metals are likely to be scattered. Nearly vertical or steeply dipping tabular deposits are in a position favorable for secondary concentration, but sulphide enrichment may be extensive also in large isodiametric deposits, or in thick deposits that stand in any attitude.

Deposits that outcropped at one time but are now covered by sedimentary rocks or by later lava flows may have been exposed to weathering and may have been enriched by oxygenating water before the beds covering them were laid down. It can not safely be assumed that the rich ores below the beds covering such deposits are primary and therefore likely to extend downward to indefinite depths. The secondary zones would obviously be related to a topography that existed long ago and not to the present one.

Systems of postmineral fractures in ore and country rock are structural features of obvious importance in the consideration of the enrichment of any ore deposit.

GLACIATION.

In comparatively late geologic time a considerable portion of North America was capped by a continental ice sheet, which removed by erosion the loose débris and the surface rock over great areas. Glaciation was most extensive in northern latitudes, but the continental glacier extended southward as far as Ohio and Missouri rivers, and smaller glaciers accumulated in the more lofty mountain ranges of

the American Cordillera. Many of the ore deposits that lay in the paths of the glaciers were planed off, and the ores in their upper zones were scattered in the rocky material which was left when the ice had melted. Erratic fragments of such deposits have been carried far from their sources and have been the cause of much fruitless prospecting.

The outcrop of an ore body may be removed gradually by erosion by water, but weathering generally precedes erosion. The solutions may leach the valuable minerals from the outcrop and may precipitate them at a lower level, where they will be preserved. But weathering does not attend erosion by ice, and chemical action at low temperatures is slight; consequently the metals present in the portions of the deposits that are removed are likely to be scattered. The extent to which the ore deposits in a glaciated region were weathered or otherwise altered by surface agencies before the glacial period began can not be estimated. The amount of rock removed by the continental ice sheet is known to be considerable, however, for the drift which it deposited is in many places more than 200 feet thick. It is probable that glacial erosion was in places equally great or greater. Whatever the amount of ice erosion, it appears to have been sufficient to remove the highly altered zones in most parts of northern North America.

As stated already, the processes of solution and enrichment are retarded in regions of low temperature. The areas in which ice erosion has been most vigorous are those in which the lower temperatures prevail to-day, and there is reason to suppose that the deposits in these areas were not so deeply altered before the glacial epoch as were similar deposits at lower latitudes. In Canada and in Alaska there are few large deposits of sulphide ores which are clearly of secondary origin. If the deposit at the Bonanza mine in the Chitina copper region, Alaska, is primary no large rich secondary sulphide deposits in Alaska are known to me. (See pp. 17 and 215.) The sulphide ores now exploited in Canada, except possibly the deposits at Cobalt, in the silver-bearing region of Ontario (which some have considered of secondary origin), and certain well-authenticated examples in British Columbia, are generally believed to be primary. I know of no important secondary deposits in New England. Small deposits of chalcocite ores were exploited in the Ely district, Vermont. In a copper deposit at Milan, N. H., where the sulphides outcrop at the very surface, no considerable amount of oxidation has taken place below 30 feet, and in general oxidation is trivial at even shallower depths. Only a little chalcocite enrichment has taken place, the secondary ore consisting of primary yellow sulphides coated with thin films of chalcocite, adding to its value probably not more than 1 per cent.

In Norway and Sweden, according to Vogt,¹ the surface has been polished clean by the Quaternary ice sheet, and secondary alteration is insignificant.

Glaciers do not erode their beds equally at all places. In their higher portions, where the ice is accumulating, pressures are greater, the ice is more rigid, and erosion is more vigorous. Near the margins, where the ice is melting, deposition exceeds erosion and the deposit of drift protects the surface from wear. These differences are very conspicuous in some mountainous sections of the West where the glaciers covered only portions of the country and the processes are more clearly shown. In some of the ranges of Montana, Colorado, and Utah, where ore deposits are numerous and varied, the evidences of mountain glaciation are conspicuously preserved. At some places the mountain glaciers seem to have removed very little of the altered ore, for the secondary sulphide zones and even the oxidized ores are intact, and some of these appear to be too extensive to have formed since the Quaternary glacial epoch. The Amethyst lode at Creede, Colo., has an extensive secondary zone, and one end of this lode was overridden by the ice in late geologic time. In general, erosion by mountain glaciers has been localized, the maximum wear taking place near the heads of the glaciers.

Erosion by the continental glaciers is also somewhat erratic, for great differences in the effect of the action of ice may be seen in a comparatively small area. In the Mesabi range of Minnesota the hard, fresh country rock is polished clean in places, whereas a few rods away and at but slightly lower elevations thick bodies of cellular, almost powdery iron-oxide ore remain intact. These facts suggest that other important secondary zones may be encountered when the area overridden by the continental ice sheet is more thoroughly developed.

THE UNDERGROUND CIRCULATION.

OPENINGS IN THE EARTH'S CRUST.

As emphasized by Van Hise in his treatise on metamorphism² the outer part of the earth's crust may be divided into three zones, differentiated by character of deformation—an upper zone of fracture, a lower zone of flowage, and a middle zone of combined fracture and flowage. The zone of fracture is near the surface. The openings in the rocks of this zone are comparatively stable because the weight of the overlying load of material is less than the crushing strength of the rock. At greater depths, where the differences in the stresses exceed the strength of the rocks, openings, if formed, would almost

¹ Vogt, J. H. L., Problems in the geology of ore deposits, in Pošepný, Franz, The genesis of ore deposits, 1902, p. 675.

² Van Hise, C. R., A treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1904, pp. 187-191; Principles of pre-Cambrian North American geology: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, p. 589.

immediately be closed by pressure. It is estimated that for all but the strongest rocks flowage would begin at depths not greater than 5 or 6 miles, where the weight of the overlying mass is greater than the crushing strength of the rocks, but there are some reasons for extending this estimate of the zone of fracture to even greater depths. This problem has recently been investigated experimentally by F. D. Adams¹ and mathematically by L. V. King.² Small holes were bored in cylinders of granite that were inclosed in hollow cylinders of nickel steel. Thus confined, the granite sustained loads of nearly 100 tons per square inch, a load more than seven times as great as that which will crush it at the surface of the earth in the usual laboratory tests. Adams concludes that, under the conditions of pressure and temperature that are believed to prevail within the earth's crust, cavities and fissures may exist in granite to a depth of at least 11 miles and may exist at still greater depths if they are filled with water, gas, or vapor, owing to the pressure exerted by the liquid or gas on their inner surfaces.

Sulphide enrichment, however, is probably confined to the upper part of the zone of fracture, and although transfers of certain materials may take place in the deeper zones, these do not come within the scope of this investigation. The deepest bodies of secondary sulphide ores now exposed lie at comparatively shallow depths; most of them less than 1,000 feet below the surface, and nearly all that have been developed lie at depths less than 2,000 feet. The depth at which precipitation takes place depends not only on the rate at which the solutions are carried downward but also on the rate at which they react on the walls of their conduits. Although openings may exist at depths of several miles, they would not become channels of circulation unless they were connected. There is without doubt a tightening of the rocks a few hundred feet below the surface, for, as pointed out by Kemp³ and by Finch,⁴ the lower levels of many deep mines are dry.

THE LEVEL OF GROUND WATER.

The terms "water table" and "level of ground water" are generally used to describe the upper limit of the zone in which the openings in rocks are filled with water. This upper limit of the zone of saturation is not a plane but a warped surface. It follows in general the topography of the country but is less accentuated. It is not so deep below a valley as below a hill but rises with the country toward the hilltops and in general is higher there than in the valleys. Although the water in the zone of saturation does not move rapidly,

¹ Adams, F. D., An experimental contribution to the question of the depth of the zone of flow in the earth's crust: *Jour. Geology*, vol. 20, 1912, pp. 97-118.

² King, L. V., On the limiting strength of rocks under conditions of stress existing in the earth's interior: *Jour. Geology*, vol. 20, 1912, pp. 119-138.

³ Kemp, J. F., The rôle of the igneous rocks in the formation of veins, in Potapny, Franz, *The genesis of ore deposits*, 1902, p. 696.

⁴ Finch, J. W., The circulation of underground aqueous solutions and the deposition of lode ores: *Proc. Colorado Sci. Soc.*, vol. 7, 1904, pp. 193-252.

it is not stationary. If there is a lower outlet, it will move toward that point. Its movements are slow, however, and it may follow a very circuitous route before it issues again at the surface. It follows the paths of least resistance, and if these are downward the water may sink to great depths before it rises, under pressure, to make its exit at some point which is lower than that at which it first entered the belt of saturation. Thus the water table may be considered a kind of indicator that registers the differences between the loss or leakage of the zone of saturation and the addition from the surface.

As the country is eroded, the water level moves downward and, within certain limits also, it changes with the seasons. In dry years it is deeper than in wet years, and in dry seasons it is deeper than in wet seasons. The difference of elevation between the top of this zone in a wet year and in a dry year is normally greater under the hilltop than on the slopes and in the valleys. In mines where the ground is open the level of ground water probably changes with every considerable rain. Consequently there is a zone that is above ground-water level in dry periods but below it in wet periods, and in moist hilly countries this zone may be of considerable vertical extent. Thus the water table oscillates, though in general it moves downward with degradation of the land surface.

THE VADOSE CIRCULATION.

Of the rain that falls on the surface a part is drained off by rills and streams, another part is evaporated, and still another part soaks deep into the ground, passes downward, and is added to the water of the zone of saturation. The zone mentioned under the preceding heading—a zone that lies above the zone of saturation and may be relatively dry during a dry period but soaked with water after a wet period—includes openings which in a relatively dry time are filled with air; consequently the water that soaks into the ground after a subsequent rain or snow is aerated and thus becomes a more active agent of solution. The downward movement of such water toward the zone of saturation has been termed the “vadose”¹ circulation. The depth or thickness of this vadose zone is variable, for its lower limit depends on the variable level of ground water. Near permanent streams or lakes and other bodies of water this limit is not much higher than they are. In moist hilly countries its depth from the surface varies from a few feet to several hundred feet. In arid regions, where the rainfall is low and evaporation is rapid, this zone may extend to much greater depths. It is, in the main, a zone

¹ Pošepný, Franz, *The genesis of ore deposits*, 1902, p. 18. Pošepný includes in the “vadose” circulation water below the “permanent water level.”

of solution; consequently, its rocks are open and circulation within it is comparatively rapid.

THE DEEPER CIRCULATION.

The circulation of the water in the belt of saturation depends on the relief of the country and on the number, continuity, spacing, and size of the openings in the rocks. Under hydrostatic head the waters in this zone move to points of less pressure and issue at points lower than those of entry. If the deposit is tight and there are no deep outlets the principal movement is shallow, following down the grade of the undulating water table. As a rule movement in the deeper zone is much slower than in the vadose zone, because the openings are less abundant and also because they are smaller, so that friction on their walls is greater. Some have maintained that the deeper circulation is fairly vigorous, but so far as may be inferred from the developments of deep mines it appears that the underground circulation, in many places at least, is exceedingly sluggish. The depths to which the solutions descend is a question concerning which there are great differences of opinion. In some rocks, under favorable structural conditions, surface waters are conducted, in porous beds or along fractured zones, several thousand feet below the surface, but in other rocks little or no water is collected at depths of more than a few hundred feet.

The shallowness of the zone of the meteoric circulation has been emphasized by Kemp¹ and by Finch.² In the copper-bearing region of Keweenaw Point, Mich., the lower ends of several shafts that penetrate many layers of bedded rocks are dry and dusty. One of these shafts is sunk about a mile below the surface, but no water is raised from the deeper levels. At Przibram, Bohemia, no water is raised from depths below 2,500 feet, although the workings extend below 3,500 feet. The water raised in the Dives-Pelican mine, Georgetown, Colo., from the sump, 2,000 feet below the surface, was not greater in quantity than that which was pumped from the mine when the bottom of the shaft was at higher levels. The drainage tunnels at Cripple Creek become nearly dry a few years after they are run, indicating that the waters in that area are stored in the funnel of the volcanic complex which is surrounded by relatively impervious granite and crystalline schists.³ In the lower levels of deep mines of Butte, Mont., there is very little water except that which flows in from higher levels. In many comparatively deep mines of the arid

¹ Kemp, J. F., The rôle of the igneous rocks in the formation of veins, in Pošepný, Franz, The genesis of ore deposits, 1902, pp. 681-809.

² Finch, J. W., The circulation of underground aqueous solutions and the deposition of lode ores: Proc. Colorado Sci. Soc., vol. 7, 1904, pp. 193-252.

³ Lindgren, Waldemar, and Ransome, F. L., Geology and gold deposits of the Cripple Creek district, Colorado: Prof. Paper U. S. Geol. Survey No. 54, 1906, p. 233.

Southwest no body of standing water has been encountered. At Tintic, Utah, according to Finch,¹ water for drilling is conducted into the mines from the surface. Many deep bore holes sunk in search of oil and water have proved to be dry. These and many other examples indicate that the water circulation is exceedingly sluggish in some regions a short distance below the surface.

On the other hand, it should be noted that large volumes of water were lifted for considerable periods from deep levels of the Comstock lode, of the Granite-Bimetallic mine in Montana, of the Commodore mine at Creede, Colo., and of a great many other mines that have been developed more than 2,000 feet below the surface. From this it appears that local differences in the underground circulation are extreme. The amount of fracturing of the deposits and especially the size of the openings seem to be the most important factors controlling the rate of the circulation. Friction that retards flow multiplies with decrease in size of channels.

THE REGION OF NEARLY STAGNANT WATERS.

The zone of the deeper circulation varies greatly in depth and vertical extent. Its water is discharged at points that are not lower than the lowest elevation of the country, and if numerous points of discharge are located along a lode that outcrops at several different elevations there will be a considerable lateral movement of the waters toward these, for the solutions move to points of less pressure. If lower rocks are saturated and their openings are filled, the solutions descending from above will find any lateral outlet that is available. In some deposits the solutions doubtless descend to points lower than the lowest outlets and rise again to issue at such outlets, but such circulation is probably slight compared to the circulation that keeps closer to the surface owing to the nearness of points of issue which are located at the surface. Where there are structures that afford passages like inverted siphons there may be a considerable movement of water below the lowest outlet, but under conditions of fairly regular spacing of openings along the lode the circulation becomes less and less vigorous as depth increases below the lowest outlet. There is thus a division, probably everywhere somewhat indefinite, between the sluggish deeper circulation and a zone of static or nearly stagnant waters below it. This conception has been clearly developed by Finch in his paper on the circulation of underground waters.² There is much evidence that in some rocks the top of this zone lies within a few hundred feet of the surface or even less, but where there are deep open fissures it may be much deeper. Finch cites considerable evidence to show that rocks are generally dry below

¹ Finch, J. W., The circulation of underground aqueous solutions and the deposition of lode ores: *Proc. Colorado Sci. Soc.*, vol. 7, 1904, p. 216.

² *Idem*, p. 209.

depths of 1,000 or 1,500 feet, except where they are strongly fractured. Long dry crosscuts, so familiar to all who have worked in deep mines, point clearly to this conclusion.

THE SEVERAL SUCCESSIVE ZONES.

DOWNWARD CHANGE IN SULPHIDE DEPOSITS.

As is clearly set forth by R. A. F. Penrose, jr., S. F. Emmons, W. H. Weed, and others, many sulphide deposits show characteristic changes from the surface down the dip. At and near the surface the deposits are generally oxidized and stained with limonite. The outcrop and the upper part of the oxidized portion of the deposit may be poor. Below this there may be rich oxidized ores; still farther down, rich sulphide ores; and below the rich sulphides, ore of relatively low grade. This lowest ore is commonly assumed to be the primary ore, from which the various kinds of ore above have been derived. The several kinds of ore have a rude zonal arrangement, the so-called "zones" being, like the water table, highly undulatory. They are related broadly to the present surface and generally to the hydrostatic level but may be much more irregular than either, for they depend in large measure on the local fracturing in the lode which controls the circulation of underground waters. Any zone may be thick at one place and thin or even absent at another. If these zones are platted on a longitudinal vertical projection it is seen that the primary sulphide ore may here and there project upward far into the zone of secondary sulphides, or into the zone of enriched oxides, or into the zone of leached oxides, or may even be exposed at the surface. The zone of sulphide enrichment (which is not everywhere present) may project upward far into the zone of rich oxidized ore, or into the zone of leached oxides, or may outcrop at the surface. The zone of sulphide enrichment nearly always contains considerable primary ore, and very commonly the so-called secondary ore is merely the primary ore containing in its fractures small seams of rich secondary minerals. The zone of enriched oxides is generally found above the lowest level reached by the water table. This zone in places extends to the outcrop. The zone of secondary sulphides in moist countries is in general below the water level. In arid countries it may be partly or entirely above the water level.

All these zones except that of the primary ore are, broadly considered, continually descending. Ore taken from the outcrop may represent what was once primary ore; afterward, enriched sulphide ore; still later, oxidized enriched sulphide ore; later still, leached oxidized enriched sulphide ore; and finally it became the surface ore or gossan. Through more rapid erosion at some particular part of the lode any one of these zones may be exposed, and hence an outcrop of ore of any character is possible.

THE OXIDIZED ZONE.

CONDITIONS IN THE OXIDIZED ZONE.

In the presence of air and water sulphide ores break down and form soluble salts and minerals that are stable under surface conditions. No metallic sulphide that is long exposed to the action of these agents remains unaltered. Iron sulphides, which are present in practically all deposits of sulphide ores, are changed to iron oxides, and such a change is attended by the liberation of iron sulphates and sulphuric acid, which under favorable conditions dissolve many of the minerals. In many deposits relatively stable basic iron sulphates are formed, but even these eventually break down.

The oxidizing zone is in the main the zone of solution. Precipitation also takes place in this zone, especially the precipitation of the oxides and hydrous oxides of iron, aluminum, manganese, and silicon. By redeposition deposits of the more valuable metals are formed also in this zone. Solution generally exceeds precipitation, however, and by solution the mass is reduced and open spaces are enlarged. In limestones many of these spaces, called "water-courses," are large enough for a man to pass through. The increase in the size and in the volume of the openings renders the downward circulation comparatively free in the zone of oxidation. Regarding the processes of solution at Bisbee, Ariz., where oxidized ores are exceptionally developed, I quote the following from Ransome:¹

The most marked physical effect of the oxidation of the ore bodies has been a great increase in the porosity of the masses acted upon. This, by enabling solutions to percolate easily through the partly oxidized zone, has greatly facilitated the migration and concentration of the desulphurized ores and their segregation in workable masses from the bulk of the limonitic and clayey "ledge matter."

The oxidized material is not only more porous but much softer and more plastic than the original mineralized limestone and hence greatly weakens by its presence the rocky structure in which it occurs. The overlying limestones, no longer adequately supported, fissure and settle down upon the soft plastic ore and gangue. The access of solutions is thus still more facilitated, and the processes of oxidation and solution proceed so much the faster. That part of the surface which is underlain by oxidizing ore bodies is thus rendered less resistant to erosion, other things being equal, than the surrounding country.

Some of the metals—for example, gold—dissolve very slowly in the zone of oxidation. If the other materials in an ore deposit are taken away, however, the ore may be enriched by decrease in volume, in the manner elucidated by Rickard.²

The hydrous oxides, once formed, are comparatively stable, and under certain conditions the more valuable metals dissolve more

¹ Ransome, F. L., The geology and ore deposits of the Bisbee quadrangle, Arizona: Prof. Paper U. S. Geol. Survey No. 21, 1904, p. 159.

² Rickard, T. A., The formation of bonanzas in the upper portions of gold veins, in *Polepny, Franz* The genesis of ore deposits, 1902, pp. 734-755.

readily than the other vein materials in the oxidized zone. Consequently the oxidized zones are in general leached of the valuable metals. Leaching is generally incomplete, however, for owing to the removal of the outcrops by erosion, new surfaces are presented to attack.

As already stated, the oxidized zone is generally above a secondary sulphide zone. As the latter is the richest part of many deposits and as the zone of oxidation is descending the processes of oxidation attack materials that are comparatively rich. In many deposits the first effect of oxidation is to convert the richer sulphides to rich oxides; consequently the lower part of the oxidized zone may be as rich as or even richer than the secondary sulphide zone.

Since copper may replace iron sulphides almost completely in the altered zones of some deposits the gossans in some regions represent the oxidation product of a chalcocite zone nearly free from iron. Thus the outcrop may be only slightly stained with iron. Some important bodies of copper ores at Butte, Mont., at Morenci, Ariz., at Bingham, Utah, and at Cananea, Mexico, have outcrops composed of light-colored kaolinized rocks that are not highly ferruginous.

SEGREGATION OF THE METALS IN THE OXIDIZED ZONE.

As a result of surface alteration the metals are at many places segregated in the oxidized zone. At Ducktown, Tenn., a pyritic copper ore is converted near the surface into a high-grade iron ore. Below the iron ore is an exceptionally rich chalcocite ore, and below this the low-grade copper ore, the original deposit from which the iron ore and the rich copper ore have been derived. At Ducktown, as in many other districts, the processes of alteration are clearly related to the water level which divides the zone of solution from the zone of precipitation of copper, but in certain districts where the water level is lower nodules of oxidizing ore show the same zonal arrangement. Many of these nodules or spheres are made up of successive shells, each inclosing a smaller one, like the layers of an onion. Although the spherical shape of some of these nodules may be original, many of them have become rounded by oxidation. Where irregular blocks are inclosed by fractures to which water and oxygen have access, processes of oxidation, extending inward from the fractures to approximately equal depths, tend to round off irregularities of the unaltered mass, because the inequalities are the more exposed. The processes may be compared to concentric weathering at the surface.

At the Southern Cross mine, near Cable, Mont., nodules of gold-bearing pyrite are surrounded by shells of limonite which clearly have been derived from the oxidation of the iron sulphide in place. Gold is concentrated in the outer shells by diminution of mass, but volume

for volume the tenor of the iron sulphide and iron oxide is approximately the same. At Leadville, Colo., according to Ricketts,¹ nodules of galena carry six times as much silver as the cerusite crusts that surround them. A number of assays cited by S. F. Emmons² show a silver content of 420 ounces per ton of galena and only 28.6 ounces per ton of the corresponding cerusite crusts. In view of the fact that the galena of Carbonate Hill averages only 145 ounces per ton,³ these figures seem to indicate addition of silver to the galena, as well as leaching of silver from the carbonate.

To illustrate the separation of copper and iron in the zone of oxidation, I quote from Lindgren, Graton, and Gordon⁴ the following description of oxidizing nodular masses in the Apache No. 2 mining district, New Mexico:

The primary ore consists here of a gangue of extremely coarse calcite with a little iron and practically no magnesia. When this is dissolved in acid there remains a skeleton of small films and grains of quartz whose presence would hardly be expected in the apparently homogeneous cleavage pieces. The calcite contains grains of chalcopyrite and small cubes of pyrite. During oxidation this primary low-grade ore becomes surrounded by crusts of secondary calcite, limonite, hematite, malachite, and chrysocolla. The iron and copper separate, the former being deposited in the recrystallized calcite as hydroxide or oxide, while the copper minerals form a thin crust directly adjoining the primary ore and gradually traveling inward as the oxidation progresses. This is exactly what happens under the more intense conditions of artificial oxidation or the roasting of chalcopyrite in metallurgical work. The heat in the presence of oxygen will gradually concentrate the copper sulphide or oxide in the center of the lump, while the ferric oxide forms a shell which can easily be knocked off.

Considered in more detail, the narrow ring of oxidized copper ore consists of alternate narrow bands of malachite and chrysocolla, the latter being due to the quartz distributed microscopically through primary calcite. The malachite always forms the inner zone and projects into the fresh calcite as tufts of slender needles. In places a thin layer of calcite will separate the copper minerals. The wide outer crust consists of recrystallized calcite which only in part has the same orientation as the central cleavage piece of primary ore. This recrystallized calcite contains limonite in flocculent masses, in places distributed concentrically, but does not carry even a trace of copper. At the outer edge of the specimen the limonite changes to dark-brown hematite.

At Bisbee, Ariz., the segregation of the metals in the zone of oxidation is shown on a grand scale. As stated by James Douglas,⁴ a large mass of ore developed between the 200 and 400 foot levels of the Copper Queen mine consists of a core of compact pyrite very lean in copper surrounded by a shell of rich copper ore. According

¹ Ricketts, L. D., *The ores of Leadville and their modes of occurrence*, Princeton, N. J., 1883, p. 37.

² Emmons, S. F., *Geology and mining industry of Leadville, Colo., with atlas*: Mon. U. S. Geol. Survey, vol. 12, 1886, pp. 553-554.

³ Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., *The ore deposits of New Mexico*: Prof. Paper U. S. Geol. Survey No. 68, 1910, pp. 55-56.

⁴ Douglas, James, *The Copper Queen mine, Arizona*: Trans. Am. Inst. Min. Eng., vol. 29, 1900, p. 531.

to Ransome,¹ a mass of pyrite was noted on the 1,000-foot level of the Lowell mine, lying generally parallel with the bedding of the limestones and in contact with partially oxidized ore both above and below. Some native copper was seen in the oxidized ore close to the pyrite. Similar residual masses of worthless pyrite surrounded by good ore, usually containing chalcocite, were seen on the 1,050-foot level of the Calumet & Arizona mine.

The processes that operate to form the small nodules are probably similar to those that operate to form the larger masses. Many details of the chemistry of these processes have not been worked out, but it is generally recognized that oxidation favors the solution of some compounds and the precipitation of others. Dilute acid in the presence of air dissolves the sulphides of both copper and iron. Iron, but not copper, is precipitated by hydrolysis of sulphates. Dilute acid in the absence of air dissolves iron sulphide but not copper sulphide, for copper sulphide is precipitated at the expense of iron sulphide if air is excluded. The spherical bodies of enriched sulphide ore in the zone of oxidation, which are crusted with lower-grade, presumably leached oxidizing ore, doubtless illustrate in a small way the same processes that result in the rearrangement of the metals in the several zones that are related to depth.

The separation of lead carbonate and zinc carbonate during the oxidation of ore bodies containing zinc and lead sulphides is conspicuously shown in some districts, especially in ore bodies inclosed in limestone. At Leadville, Colo., deposits of sphalerite, galena, and pyrite are overlain by large oxidized ore bodies, some of which consist of argentiferous cerusite containing but little zinc and others of iron-stained smithsonite containing little lead. At some places a zone of smithsonite is below one of lead carbonate. At the Kelly mine, in the Magdalena district, N. Mex., these processes have taken place on a smaller scale but are very clearly indicated. There, according to Lindgren, Graton, and Gordon,² the primary ore consists of zinc blende, magnetite, a little pyrite, and galena. As stated by these writers—

The depth of oxidation is about 300 feet. * * * In the oxidized stopes nearer the surface the zinc and lead part company. The oxidized zinc ores form wide stopes in which caves large enough for a man to crawl into are coated with beautiful botryoidal, light-green masses of smithsonite. The crust of this material is almost 3 inches thick, and underneath is a dark powdery material rich in manganese but also containing much zinc. The lead stopes are much smaller and are composed of almost pure "sand carbonate" with occasional bunches of galena.

¹ Ransome, F. L., The geology and ore deposits of the Bisbee quadrangle, Arizona: Prof. Paper U. S. Geol. Survey No. 21, 1904, p. 146.

² Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: Prof. Paper U. S. Geol. Survey No. 68, 1910, p. 55.

DEPTH OF THE OXIDIZED ZONE.

The depth of the zone of oxidation and the extent of oxidation within that zone depend upon the permeability of the ore and its character and composition. Conditions differ greatly in different districts and even in different deposits in the same district. The depth of thorough oxidation is generally less than the depth of the vadose circulation, for oxidation follows the depression of the water level. Where the ground-water level has been depressed by relatively rapid climatic change rather than by the gradual downward migration of ground water that attends the normal degradation of a country, the rate of its depression may be more rapid than that of the zone of oxidation, and in consequence the sulphide ores may be marooned in the vadose zone. In an arid country oxidation is probably slow, for it depends in a measure on the supply of oxygen-bearing waters. Thus at Tonopah, at Morenci, and in some other districts in the Southwest the lower limit of oxidation has lagged far behind the downward-migrating water level.

Some deposits are oxidized to great depths. At Bisbee, according to Ransome,¹ partial oxidation has been noted at depths more than 1,600 feet below the surface. At Tintic recent developments have exposed oxidized ores more than 2,000 feet below the surface. The Old Abe mine, in the White Oaks district, Lincoln County, N. Mex., according to Lindgren, Graton, and Gordon, has been worked to a depth of 1,380 feet, yielding rich oxidized ores.² The water level in this mine is 1,300 feet below the surface. In the Brooklyn mine at Bingham, Utah,³ oxidation is said to extend 1,450 feet below the surface. In the Snowstorm mine, in the Coeur d'Alene district, Idaho, according to Ransome, carbonates of copper are found about 1,200 feet below the outcrop of the lode.⁴ At Creede, Colo., partial oxidation has extended locally more than 1,000 feet below the surface.

At Tonopah, Nev.,⁵ the depth of oxidation is variable. In veins that outcrop oxidation has taken place locally to depths greater than 700 feet. Veins which do not outcrop but which are capped by volcanic rocks later than the ore show comparatively little oxidation. A single fracture line or a fault line may divide the oxidized from the unoxidized ore and rock. In this district no standing ground

¹ Ransome, F. L., written communication.

² Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: Prof. Paper U. S. Geol. Survey No. 68, 1910, p. 60.

³ Boutwell, J. M., Economic geology of the Bingham mining district, Utah: Prof. Paper U. S. Geol. Survey No. 38, 1905, p. 215.

⁴ Ransome, F. L., and Calkins, F. C., The geology and ore deposits of the Coeur d'Alene district, Idaho: Prof. Paper U. S. Geol. Survey No. 62, 1908, pp. 150-152.

⁵ Spurr, J. E., Geology of the Tonopah mining district, Nevada: Prof. Paper U. S. Geol. Survey No. 42, 1905, p. 90.

water has been encountered in the mine workings, which extend to depths greater than 1,100 feet.¹

At Przibram, Bohemia, in a comparatively moist climate, oxidation extends, according to Beck, from 200 to 900 feet below the surface. In some other moist districts, as at Ducktown, Tenn., the oxidized ores are not more than 100 feet below the present surface.

At Butte, Mont., according to Reno Sales,² in the vicinity of the St. Lawrence and Mountain View mines, the depth of oxidation is nearly 400 feet, although in many parts of the camp it is only 10 feet. The depth of oxidation in this district depends largely on the composition of the country rock—to a greater degree, in fact, than on the topographic features. The more complete the alteration and pyritization the greater the depth of oxidation. In the central copper area, where the “granite” is strongly altered and pyritized, the upper limit of sulphides is roughly a horizontal plane, although the surface contours in the same area show variations of 300 feet. Over the remainder of the copper area the average depth of oxidation is approximately 50 feet. The depth of oxidation in the veins is influenced to a slight degree by the physical character of the veins themselves. Under like conditions a quartz vein is oxidized to a greater depth than a fault or “granite vein,” owing to the greater impermeability of the clay and crushed “granite” of veins of the latter class.

At Tintic, Utah, the limit of oxidation in fractured limestone is at least 2,000 feet deep, but the ground-water level and zone of unaltered sulphides in igneous rocks scarcely half a mile away is only 200 or 300 feet from the surface.³

At Cripple Creek, Colo., partial oxidation is found in some places at depths of 1,200 feet,⁴ but in other places it is relatively shallow.

SUBMERGED OXIDIZED ORES.

As already stated, the oxidized ore is generally above the ground-water level, and in arid countries oxidation is seldom complete at depths considerably above that level. In deep mines little smears or veinlets of oxidized material, generally a mixture of kaolin and limonite or of kaolin and manganese oxide, are found at considerable depths. In moist countries such veinlets were probably deposited below the water level. As the solutions descend, their acidity is reduced, and some of the metals which may be held in acid solutions would be precipitated by a decrease of acidity.

¹ Spurr, J. E., *op. cit.*, p. 96.

² Sales, R. H., *Superficial alteration of the Butte veins*: *Econ. Geology*, vol. 5, 1910, p. 19.

³ Tower, G. W., Smith, G. O., and Emmons, S. F., *Tintic Special folio* (No. 65), *Geol. Atlas U. S.*, U. S. Geol. Survey, 1900, p. 5. Emmons, S. F., *The secondary enrichment of ore deposits*, in *Poëpny, Franz*, *The genesis of ore deposits*, 1902, p. 438. Lindgren, Waldemar, oral communication.

⁴ Lindgren, Waldemar, and Ransome, F. L., *Geology and gold deposits of the Cripple Creek district*, Colorado: *Prof. Paper U. S. Geol. Survey No. 54*, 1906, p. 196.

Extensive oxidation is probably limited to those parts of deposits that lie above the ground-water level at the time of oxidation. In some deposits, however, the ores are extensively oxidized below the water level. According to B. S. Butler,¹ the ores of the Harrington-Hickory mine, near Milford, Utah, are oxidized at least 100 feet below the present water level. At Bisbee, Ariz., the depth of oxidized ore ranges from 200 to 1,600 feet and the deeper oxidized ores are submerged. As shown by Ransome (p. 182), the altered ores are related to a tilted pre-Comanche erosion surface rather than to that existing to-day.

Where ore bodies are extensively oxidized far below the ground-water level it is reasonable to infer that the level of the ground water has risen. The amount of atmospheric oxygen that water may dissolve and carry far below the water level is very small (see p. 90) and probably would be insufficient to oxidize large masses of sulphides, even in a comparatively long period.

TRANSITIONS BETWEEN OXIDIZED AND SULPHIDE ORES.

In moist countries, where the level of ground water is near the surface, the transition between the almost completely oxidized ore and the unoxidized sulphides is generally abrupt. This is especially noticeable in the pyrrhotitic copper ores of Ducktown, Tenn., where the contact between the two is at some places as sharp as a knife blade. In pyrrhotitic ores of the Encampment district, Wyoming, chalcocite ores occur immediately below the gossan.² In the pyritic copper ores of Butte, Mont., according to Sales, the transition is sharp. He says:³

Examined from the surface downward the oxidized portion of a copper vein will show but little variation in physical character or mineral composition between the outcrop and the sulphide ore. The line of separation marking the change from oxidized to sulphide ore is very sharp and clean cut. There is no partial oxidation of the vein; no mixture of sulphides and oxides. The entire change in any single cross section of a vein takes place within 2 or 3 feet vertically. Generally the sulphide ore, through slight changes in the relative abundance of certain minerals, indicates the proximity of the oxides, while in the case of the oxides there is seldom, if ever, any change to indicate a nearness to sulphides. In the copper belt the minor veins, stringers, iron pyrite seams, country rock, etc., are all oxidized and bear the same relation to the surface and to depth of oxidation as do the large veins.

In some other districts, however, there is no such sharp dividing line between the oxide and the sulphide ore. At Bingham, Utah, according to Boutwell,⁴ the transition from the zone of oxidation to

¹ Oral communication.

² Spencer, A. C., The copper deposits of the Encampment district, Wyoming: Prof. Paper U. S. Geol. Survey No. 25, 1904, p. 55.

³ Sales, R. H., Superficial alteration of the Butte veins: Econ. Geology, vol. 5, 1910, p. 19.

⁴ Boutwell, J. M., Economic geology of the Bingham mining district, Utah: Prof. Paper U. S. Geol. Survey No. 38, 1906, p. 221.

the zone of sulphide enrichment is gradual, as it is also at Morenci, Ariz., where the zone of secondary sulphides is oxidized through a considerable vertical distance. Says Lindgren:¹

The oxidation does not extend down to any well-defined water level, which must be far below the deepest workings, but acts most irregularly, sometimes leaving fresh metamorphic limestone at the surface and again reaching down to a depth of 400 feet along fissures and faults. The present ore bodies probably fell an easier prey to oxidation by reason of their richness in sulphides and their favorable exposure to percolating waters. In such position are the upper ore bodies of the Detroit and Manganese Blue. In other cases the oxidation was facilitated by means of fault planes and porphyry dikes.

At Bisbee, Ariz., the zone of transition between the oxide and sulphide ore is extensive. According to Ransome:²

Within the transition zone between completely oxidized and unaltered sulphide ores, which has a maximum depth or thickness of about 900 feet, the oxidizing processes are controlled to a large extent by recent irregular fissuring and by the relative permeability of the various sulphide masses to generally descending solutions. Fissures cutting through masses of lean pyrite are almost invariably accompanied by streaks of rich ore, often containing chalcocite, together with cuprite and native copper. Where there are several such fissures near one another important ore bodies result. The general association of profitable ore with fissured, broken, permeable ground is well recognized in practical operations and turned to good account in underground exploration.

THE SECONDARY SULPHIDE ZONE.

POSITION AND EXTENT.

The secondary sulphide zone is generally below a zone of oxidation. It is not everywhere developed, not even in copper ores that are capped with gossan. Examples of such deposits are cited on a following page. In many deposits the transition between the oxidized and secondary sulphide zone is sharp, being essentially at the ground-water level. In such deposits the secondary ores extend downward to various distances below the water level. The vertical extent of the secondary zone differs widely in different districts. In some of the districts of the southern Appalachians the chalcocite zones occupy only a few feet vertically. At Ducktown, Tenn., in all except one mine the average thickness of the secondary chalcocite zone is probably between 3 and 8 feet, but some secondary chalcopyrite is developed far below this zone. In the East Tennessee mine, in this district, the vertical range of chalcocite is about 125 feet. In the Encampment district, Wyo., the vertical extent of chalcocite is at least 200 feet. In the disseminated deposits in porphyry at Bingham, Utah, the zone of workable sulphides, mainly chalcocite

¹ Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 197.

² Ransome, F. L., The geology and ore deposits of the Bisbee quadrangle, Arizona: Prof. Paper U. S. Geol. Survey No. 21, 1904, p. 145.

and chalcopyrite, has an average vertical extent of 418 feet,¹ and owing to the rugged topography the vertical range is much greater. At Morenci, Ariz., the belt of maximum deposition of secondary chalcocite is in general from 200 to 400 feet below the surface, although veins of chalcocite are said to be encountered at greater depths, especially in the Coronado mine. In this mine also, according to Lindgren,² chalcocite in places reached the surface. At Bisbee, Ariz., chalcocite, partly oxidized, is found within 200 feet of the present surface and extends to depths at least 1,500 feet below the surface. At Globe, Ariz., in the Old Dominion mine, chalcocite has been found more than 1,200 feet below the surface and has a vertical range of at least 800 feet. In the Miami Inspiration ore zone, according to current reports, chalcocite is found 900 or 1,000 feet below the surface. In all these districts chalcocite is regarded as a mineral which is in the main if not altogether secondary. At Butte, Mont., chalcocite has been found at depths 2,800 feet below the surface. In the upper levels of the Butte mines secondary chalcocite is abundant, but recent investigations, especially those of Reno Sales, indicate that the chalcocite of the deeper levels is probably primary. Except at Butte no data now available indicate deposition of secondary chalcocite at depths greater than 1,500 feet below the outcrop. It is not at all improbable, however, that secondary chalcocite deposited at greater depths may be revealed by future exploration.

Examples of enrichment of silver sulphide deposits at depths from 1,000 to 1,200 feet below the surface are well authenticated. Doubtless secondary deposits of silver occur at greater depths, but it is questionable how far the several species of the silver-bearing minerals may indicate geologic processes. I know of no examples of the precipitation of appreciable amounts of gold by descending solutions at depths more than 1,000 feet below the surface. In general, gold that is dissolved by surface waters is precipitated at relatively shallow depths.

The data reviewed above show that no definite depth can be fixed below which processes of enrichment are not effective. The maximum precipitation occurs at comparatively shallow depths, however, and there is little reason to suppose that these processes are effectively operative in the deeper part of the zone of fracture. The depth to which the metals are carried depends on local climatic conditions, permeability, and the chemical or mineralogic environment.

¹ Seventh Ann. Rept. Utah Copper Co., Dec. 31, 1911.

² Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 210.

RELATION TO THE WATER LEVEL.

The ground-water level, the so-called water table, has frequently been regarded as indicating the top of the secondary sulphide zone at the time that zone was formed. As has been stated, the water level is not stationary but oscillates, although it tends to move downward as the major drainage channels approach grade. If the water level is comparatively high or if the lode is much fractured, and particularly if it contains large spaces, there is probably but little precipitation of the secondary sulphides above the water level. There are two reasons why this should be true; one is that the solutions descend in open rocks at a comparatively rapid rate through the fractured and partly weathered zone of somewhat cellular ore above the shallow water level, and the other is that several of the sulphides of the more valuable metals that are dissolved readily in an oxidizing environment are not readily precipitated in such an environment. If the rocks are open atmospheric oxygen should find ready access to the ore above the zone of saturation. But even if precipitation should take place the sulphides precipitated would later be exposed again to oxidation and solution.

The sulphides below the water level are protected from the oxygen of the air, however, and solution of some metals is retarded if not prevented. The solution in acid sulphate of copper sulphide, silver compounds, and gold requires an oxidizing agent. It is well known that a small concentration of ferrous sulphate, which is surely present in the reducing zone below the water level, will drive gold and silver from solution. Copper sulphide, which dissolves readily in sulphuric acid in the presence of air, is not dissolved in its absence. Hydrogen sulphide is generated by the action of acid on several sulphides and in the presence of the faintest trace of hydrogen sulphide copper sulphide is not dissolved—not even in boiling concentrated acid.¹ Thus it would be supposed that under these conditions the solution of copper, silver, and gold would be inhibited at ground-water level or a short distance below it. Since a liter of water can absorb under surface conditions only about 6.84 cubic centimeters of atmospheric oxygen, the amount carried dissolved, even in a saturated solution, can not be great. The oxygen that is made available by the hydrolyzation of water when ferric sulphate is reduced to ferrous sulphate and that which combines to form the higher oxides of manganese might delay reduction, but the delay would be only temporary. Although oxygen is required for the solution of gold, silver, and copper, the sulphides of zinc and at least some of the sulphides of iron might be dissolved at depths considerably below water level, for they

¹ Allen, E. T., oral communication.

are attacked by acid sulphate even in the absence of an oxidizing agent.

Many deposits of secondary sulphide ore in the arid Southwest are well above the present ground-water level. The lower limits of some of these deposits have been reached by mining, and below some of them lie considerable bodies of pyrite and chalcopyrite ore which have been penetrated by mine workings that encountered no standing underground water. As has been already stated, the climate in this area has changed from humid or subhumid to arid in comparatively recent time, and it is possible that some bodies of secondary sulphide ore have been marooned by the rapid descent of the ground-water level that attended the change. At Morenci, Ariz., nearly all the mines are dry in and below the chalcocite zones of these deposits. Of these Lindgren¹ says:

Chalcocite perhaps forms at the present time in the upper levels of the belt occupied by this mineral where copper-sulphate solutions from oxidizing chalcocite above are abundant and free oxygen absent. * * * Direct oxidation has, in fact, already penetrated to the deepest levels attained in the pyritic zone; at present it works here chiefly along fissures and seams but is probably slowly spreading.

I regard the chalcocite zone as formed about an ancient water level, much higher than the present. During the epoch of the Gila conglomerate the water level was surely at least several hundred feet higher than it is now, and it was probably still higher during Tertiary time, in which a moist climate most likely prevailed.

PRECIPITATION OF SULPHIDES ABOVE THE WATER LEVEL.

In arid districts, where the water level lies very deep, the descending metal-bearing solutions may encounter a reducing environment in the so-called vadose zone, especially in rocks that contain only minute openings, through which the water soaks downward from the surface, excluding the admission of any considerable amount of air. It would be supposed that the oxygen present in such waters and in the imprisoned air would be used up before the descending solutions encountered any zone of permanent saturation, or that the solutions might become reduced before reaching ground-water level, so that the metals could readily be precipitated.²

Any former water level doubtless maintained the usual relation to the topography that existed when it prevailed, and it is generally untenable to assume that the topography which controlled a former water level in a region where the climate has changed recently was very different in its major features from the present topography. Stope sheets and other available published information show that many of the chalcocite zones in copper deposits of arid regions have

¹ Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district: Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 206.

² Finch, J. W., The circulation of underground aqueous solutions and the deposition of lode ores: Proc. Colorado Sci. Soc., vol. 7, 1904, p. 238.

a pretty definite relation to the major features of the present topography, and it therefore seems possible that when they were formed they bore the usual relation to the water level then prevailing. The disseminated chalcocite ores of Miami, Ariz., are, however, not definitely related to the present topography, which was apparently developed after the main period of enrichment.¹ At Ray also, according to Ransome,² the layer of disseminated chalcocite ore has many irregular undulations that apparently have no dependence on the present topography.

It is not at all unlikely that secondary sulphide ores have formed independently of any present or past water level. As stated by Finch,³ deposits exposed to processes of alteration in an arid region may lie in gaseous zones that are analogous to the aqueous zones of more humid regions. Oxygen predominates in the surface zone, whereas carbon dioxide and other heavier gases may prevail at greater depths. Thus in an arid region there may be an oxidizing gaseous zone and below it a reducing gaseous zone in which precipitation may take place in the absence of oxygen. Circulation by evaporation would be possible in the lower zone.

Precipitation by evaporation is undoubtedly a factor to be considered in shallow oxidizing zones and may account for the veinlets of clayey limonite that are found in cracks in some sulphide ores at depths considerably below the zones of nearly complete or well-advanced oxidation. The material precipitated by the evaporation of the mineral waters should be chemically similar to that deposited by evaporation under surface conditions, and, so far as analyses show, mineral waters that accomplish sulphide enrichment generally carry iron, aluminum, and other metals of low value greatly in excess of the more valuable metals. Unless, by processes of selective precipitation, certain compounds only could be removed from the solutions in depth, nearly all of the material dissolved in the oxidizing environment and carried below into the reducing environment would be precipitated. There would be a downward circulation of water and dissolved mineral matter. The upward circulation of evaporated water might carry some of the dissolved salts, but few data are available on this point. Weed states that ferrous, copper, and zinc sulphates are carried by the moisture of air circulating in mine openings. He thus accounts for efflorescence of these salts on mine workings.⁴ Since mineral matter could not readily escape, however, the enrichment that could take place where downward-moving aqueous solutions could not reissue would

¹ Ransome, F. L., this bulletin, p. 185.

² Ransome, F. L., this bulletin, p. 187.

³ Finch, J. W., The circulation of underground aqueous solutions and the disposition of lode ores: *Proc. Colorado Sci. Soc.*, vol. 7, 1904, p. 240.

⁴ Weed, W. H., *Geology and ore deposits of the Butte district, Montana*: Prof. Paper U. S. Geol. Survey No. 74, 1912, p. 99.

depend on the sum total of the openings available, for appreciable replacement under these conditions would probably not occur. The secondary materials that are deposited under such conditions as a whole would not be much if any richer than the residues of descending waters, although even under these conditions the valuable minerals might be segregated somewhat by selective precipitation.

TEXTURES OF SECONDARY SULPHIDE ORE.

In the zone of oxidation solution ordinarily much exceeds precipitation. The oxidized ore is almost invariably of spongy, open texture and contains numerous solution cavities. In the secondary sulphide zone solution does not exceed precipitation to the same extent. In the sulphide zone numerous solution cavities may be developed, but these are likely to be filled, partly or completely, by secondary minerals. The texture of secondary sulphide ore varies widely. Some of the chalcocite ore of Ducktown, Tenn., is little more than a sponge of chalcocite from which iron, copper, and other sulphates have been dissolved. On the other hand, some secondary sulphide ores consist largely of massive chalcocite inclosing numerous primary minerals, the pore space in the ores being quite subordinate.

The solution of primary sulphides and the precipitation of secondary sulphides may go on simultaneously, the secondary minerals replacing the primary. The best proof of replacement is offered where the later minerals have assumed the crystal forms of the earlier minerals. Pseudomorphs of chalcocite or covellite after pyrite, chalcopyrite, or zinc blende are the most common. Such replacements of pyrite are clearly shown in the Miami-Inspiration ore zone at Miami, Ariz.,¹ and at other places. Examples scarcely less suggestive are found in districts where masses of primary sulphide not having crystal form but of distinctive occurrence have been replaced by secondary ores. In the No. 20 mine near Ducktown, Tenn., where the primary ore, consisting chiefly of massive pyrrhotite, pyrite, and chalcopyrite, includes small rounded masses of quartz, garnet, and actinolite, the secondary ore consists of chalcocite and other minerals and includes similar rounded masses of gangue minerals partly dissolved. At Morenci, Cananea, Bingham, Ely, Santa Rita, and in other districts containing disseminated deposits of secondary chalcocite, where the mineralized material below the secondary zone consists of a granular or a porphyritic igneous rock containing numerous small masses and veinlets of sulphide ore, chiefly pyrite and chalcopyrite, the same rock in the secondary zone contains small masses and veinlets of chalcocite, with some pyrite and chalcopyrite, showing an arrangement of spacing similar to that shown by the minerals in the lower zone. Such evi-

¹ Ransome, F. L., *Criteria of downward sulphide enrichment: Econ. Geology*, vol. 5, 1910, p. 214.

dence of replacement is scarcely less convincing than pseudomorphs having the regular boundaries of older crystals. In some secondary deposits the small rounded cores of an older sulphide are coated over with shells of the secondary sulphide. As pointed out by Irving,¹ this in itself is evidence of replacement. That solution and precipitation went on simultaneously is indicated in such deposits by the even spacing of the cores. If solution had been completed before precipitation began, the small, rounded, partly dissolved masses would have settled and would have been massed closer. Of the chalcocite ore of the Old Dominion mine, at Globe, Ariz., Ransome² says:

When the chalcocite is examined closely, particularly with a lens, it shows an indistinct unevenness of texture suggestive of the obscurer forms of pisolitic structure observed in some bauxites. Critical scrutiny of the inclosed grains of pyrite discovers the fact that their outlines are rounded and that the chalcocite has a more or less distinct concentric, shelly structure around each grain. These facts at least strongly suggest that the chalcocite has been formed at the expense of the pyrite and that the minute structure observable in chalcocite now free from pyrite records the former presence of that mineral and its subsequent replacement by the sulphide of copper.

Much of the material which is generally termed secondary sulphide ore consists essentially of shattered and fractured primary sulphide ore, the cracks in which are filled with later sulphides or with angular fragments of the earlier sulphides crusted over with those that were introduced later. Such textures do not invariably indicate processes of sulphide enrichment by descending solutions. Many authentic examples show that, in the course of primary mineralization, the ore first deposited has been fractured and that solutions from below have deposited later sulphides in the fractures. In many deposits, moreover, the later sulphides are richer than the original fractured ore.

Pseudomorphous replacement indicates a change of physical conditions or of chemical environment. Minerals that were stable under certain conditions have been dissolved and other minerals have simultaneously been deposited. On the other hand, fractured ore cemented by later minerals may be a result of normal and perhaps continued deposition from below. If, however, the minerals that fill the later cracks are those that are commonly formed by descending solutions, and if they do not persist in depth, the assumption that they are secondary may with considerable confidence be regarded as confirmed.

In many deposits the genesis of such later veinlets is perplexing. As the matter now stands, the mineralogic criteria are unsatisfactory, for few if any of the sulphides are formed invariably under a single set of conditions.

The texture of the secondary veinlets is important, however, and it may throw considerable light on their genesis. Concerning this point

¹ Irving, J. D., *Replacement ore bodies*, in *Types of ore deposits*, San Francisco, 1911, pp. 289-290.

² Ransome, F. L., *Geology of the Globe copper district, Arizona*: Prof. Paper U. S. Geol. Survey No. 12, 1903, p. 121.

certain observations by Hynes¹ on ores from the Mina Mexico vein, Sonora, Mexico, are noteworthy. The polished surfaces of several specimens prepared by him showed primary ore composed of pyrite and quartz, not containing any antimony mineral, cut by veinlets of ore composed of tetrahedrite and quartz. In the later veinlets the quartz is everywhere inclosed in the tetrahedrite and is generally idiomorphic. Its crystals are distributed with great regularity through the tetrahedrite, suggesting definite or eutectic proportions.

So far as is now known the crystallization of minerals in eutectic proportions does not occur in descending sulphate waters. The texture of the chalcocite ores of Virgilina should be mentioned in this connection. In the upper levels of the mines the ore is cut by small veinlets of secondary chalcocite, but polished surfaces of ore from the lower levels, as shown by F. B. Laney,² reveal an intimate intergrowth of chalcocite and bornite which suggests the pattern of a graphic granite. Some of Laney's sections³ are particularly suggestive of precipitation under conditions that prevail at great depths and of processes of crystallization that are not known to operate under the temperatures and pressures that prevail in the zone of sulphide enrichment.

When in the course of the deposition of ores the minerals are deposited layer on layer in open spaces, the minerals forming the last layer or crust may differ from those formed earlier, and when cavities are broken open the minerals last deposited appear to be of late age. The position of the mineral lining the cavity does not certainly indicate that it was deposited by descending waters, for the last ores deposited by ascending waters in open spaces would be in a similar position. If, however, the walls of cavities and fractures are coated with the hydrous oxides of iron or manganese, and if sulphides have formed along with these oxides, there is small probability of error in determining whether the sulphides were formed by ascending or descending solutions, for the hydrous oxides are rarely deposited with primary sulphide ores. Likewise the intimate association of native metals with such hydrous oxides is generally evidence of deposition by oxidized descending solutions.

¹ Hynes, D. P., Notes on the geology of the Mina Mexico vein: *Econ. Geology*, vol. 7, 1912, pp. 280-286. See also Weed, W. H., *Geology and ore deposits of the Butte district, Montana*: Prof. Paper U. S. Geol. Survey No. 74, 1912, p. 76 (fig. 13, showing chalcocite inclosing idiomorphic crystals of quartz and pyrite).

² Laney, F. B., The relation of bornite and chalcocite in the copper ores of the Virgilina district of North Carolina and Virginia: *Econ. Geology*, vol. 6, 1911, pp. 399-411.

³ See especially that figured on Pl. VII, fig. 2, in the paper just cited.

ESTIMATES OF VERTICAL EXTENT OF PORTIONS OF LODES ERODED.

Where there is reason to suppose that the primary ore was of approximately uniform composition before secondary alteration took place, it is possible to estimate the vertical extent of the portion of the deposit that has been eroded. As already stated, the ore in the secondary zone generally contains the valuable metals that were present in the primary ore, those that were leached from the oxidized zone above the secondary sulphide ore, and those that were leached from the portion of the deposit that has been removed—the metals that were carried downward by solutions in advance of erosion.

Estimates made for the Granite-Bimetallic lode, Philipsburg, Mont., indicate that at least 1,600 feet of material like the primary ore in the bottom of the mine was required to supply the valuable minerals in the secondary sulphide zone, in addition to those of the primary ore and any that may have been dissolved from the oxidized zone and reprecipitated below. Estimates for Ducktown, Tenn., on the other hand, show that the valuable minerals in the secondary sulphide zone may be fully accounted for by the reconcentration of copper formerly in the leached zone now exposed, and that the copper that was present in the part of the lodes removed by erosion was scattered, probably while the region was at base-level.

If x equals the vertical extent in feet of the part of the lode which has been removed from above the present apex, a equals the vertical extent in feet of the leached zone, b equals the vertical extent in feet of the enriched zone, l equals the values¹ remaining in the leached zone, e equals the values in the enriched zone, and p equals the values¹ in the primary ore, the following formula may be applied to ascertain the number of feet removed:

$$x = \frac{a(l - p) + b(e - p)}{p}$$

This formula does not take into account the changes in mass² in the ore itself nor the pore space formed, and it is recognized, of course, that many other factors may modify the results; for the values may not all be reconcentrated, and the primary ore, before alteration and enrichment, may not have been of equal richness throughout the deposit. The estimates therefore give only a rude approximation, but one which may be used, in connection with other geologic data, as a check on conclusions regarding the minimum amount of erosion that has taken place since the primary ore was deposited.

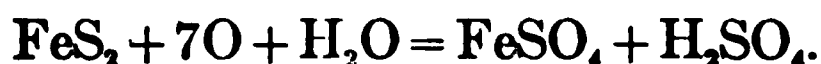
¹ Assay contents per ton.

² If value can be expressed as assay contents per unit volume, changes in mass are accounted for.

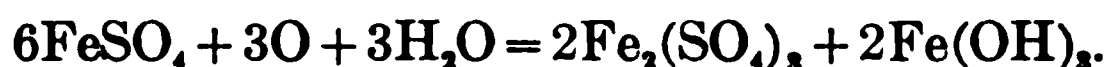
CHEMISTRY OF SULPHIDE ENRICHMENT.

EXPERIMENTAL DATA ON THE SOLUTION AND PRECIPITATION OF THE METALS.

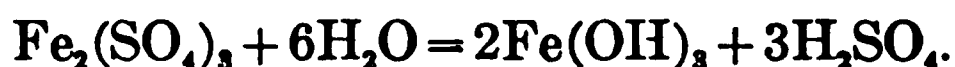
The oxidation of pyrite is considered by many to proceed as follows:¹



This equation does not express intermediate steps, nor does it represent the final products. Ferrous sulphate in the presence of atmospheric oxygen will be oxidized to ferric sulphate or to ferric sulphate and ferric hydroxide:



The hydrolyzation of ferric sulphate may first give a basic ferric sulphate,² but this subsequently breaks down, forming ferric hydroxide and sulphuric acid, as indicated below:



Ferric hydroxide probably corresponds to the mineral limnite, which on dehydration would give limonite:



According to Stokes³ the oxidation of pyrite by ferric sulphate should be regarded as taking place by two independent reactions:



In the presence of air the ferrous sulphate formed would change again to ferric sulphate.

A. N. Winchell⁴ treated powdered pyrite containing a trace of copper to dripping aerated water. At the end of ten months 300 grams of pyrite had lost 0.2 gram and the solution circulating through the pyrite had gained, per liter of the solution, the amounts indicated below:

	Milligrams.
$\text{Fe}_2(\text{SO}_4)_3$	27.68
H_2SO_4	5.7
Ferrous iron	Trace.
SO_3	Trace.

¹ Allen, E. T., Sulphides of iron and their genesis: Min. and Sci. Press, vol. 103, 1911, pp. 413-414. Gottschalk, V. H., and Buehler, H. A., Oxidation of sulphides: Econ. Geology, vol. 7, 1912, pp. 15-34.

² Penrose, R. A. F., jr., The superficial alteration of ore deposits: Jour. Geology, vol. 2, 1894, p. 293. Brauns, Reinhard, Chemische Mineralogie, Leipzig, 1896, p. 368.

³ Stokes, H. N., On pyrite and marcasite: Bull. U. S. Geol. Survey No. 186, 1901, p. 15.

⁴ Winchell, A. N., The oxidation of pyrite: Econ. Geology, vol. 2, 1907, pp. 290-294.

In the total solution there was—

	Milligrams
$\text{Fe}_2(\text{SO}_4)_3$	332
H_2SO_4	68

Grout¹ repeated these experiments, subjecting the powdered mineral to repeated drying. In a year the specimens had lost from 0.015 to 0.057 per cent. These losses are of the same order as those shown by the figures obtained by Winchell, namely, 0.067 per cent.

Buehler and Gottschalk² made numerous experiments with distilled water, leaching powdered sulphides to determine the nature of the alteration products. The finely powdered sulphides were placed upon filter paper spread upon a Hirsch filter plate, which was fitted in a 6-centimeter funnel. The sulphides were then washed twice daily with distilled water, the filtrate being caught in a flat-bottomed flask. The sulphides were treated alone and also when mixed with pyrite or marcasite or some other natural sulphide.

A series of the filtrates obtained from marcasite alone and from marcasite mixed with galena, sphalerite, and copper sulphides were tested for free sulphur dioxide, sulphites, and thiosulphates, but none of these compounds were present.

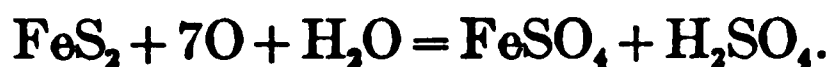
In experiments with pyrite the residue left on the funnel was treated with carbon disulphide to test for the presence of free sulphur. No sulphur was found in a series of eight experiments, but a 10-pound sample of marcasite similarly treated showed the presence of free sulphur.

Tests for the presence of hydrogen sulphide as a possible decomposition product of these sulphides were made in an apparatus through which air could be drawn. The air was passed slowly through lead solution to free it from any hydrogen sulphide; it was then passed through a tube in which finely ground sulphide was placed; finally the air was again washed in lead solution. The sulphides were washed twice daily with water. After four months' continuous treatment there was no sign of blackening of the lead solution, indicating the absence of even traces of hydrogen sulphide. The following analysis of the solution and precipitate in the flask indicates hydrolysis:

Solution, 1,068 cubic centimeters.

FeSO_4 , 0.0602 gram; $\text{Fe}_2(\text{SO}_4)_3$, 0.1799 gram; SO_3 (excess), 0.2697 gram; Fe_2O_3 (in the precipitate), 0.0218 gram.

The conclusion of Gottschalk and Buehler is that the oxidation of pyrite in water proceeds according to the reaction—



¹ Grout, F. F., The oxidation of pyrite: *Econ. Geology*, vol. 3, 1908, pp. 532-534.

² Buehler, H. A., and Gottschalk, V. H., Oxidation of sulphides: *Econ. Geology*, vol. 5, 1910, pp. 28-35; vol. 7, 1912, pp. 15-34.

This does not involve the generation of hydrogen sulphide, of sulphur dioxide, or of more than an exceedingly small amount of sulphur.

In this connection it is noteworthy that these experiments were carried on with distilled water with very free access of air. Dilute acid solutions acting upon some sulphides of lead and zinc and upon ferrous iron will generate hydrogen sulphide. (See p. 59.)

In several experiments by Gottschalk and Buehler¹ the powdered sulphides spread on a filter were washed twice daily with distilled water. In most of these experiments the sulphates were passed through 60-mesh screens and caught on 80 or 100 mesh screens, so that the powders were of approximately equal fineness. In some experiments galena was caught on 200-mesh screens, giving relatively greater surfaces for attack. Equal masses, not equal volumes, of the several minerals were taken.

In most experiments the accumulated washings were about 500 cubic centimeters. Pyrite, marcasite, galena, sphalerite, and enargite were attacked. Each of the metals was oxidized to sulphate and washed through the filter. Pyrite and marcasite were oxidized to ferric and ferrous sulphate and to sulphuric acid. Zinc was oxidized to zinc sulphate and washed through. Galena was oxidized to lead sulphate, but most of it remained on the filter, though some washed through; of the part that washed through a little was deposited in the flask as lead sulphate. Hydrogen sulphide and sulphur dioxide were not identified in any of these experiments, although in some of the filtrates there was a loss of sulphur which is not accounted for.

Each sulphide when treated alone was dissolved rather slowly, but when two were treated together the action on one of them was greatly accelerated and that on the other retarded. Sphalerite dissolved more readily in the presence of pyrite. The acid generated by the oxidation of iron was not the only factor that favored solution, for when the iron sulphide was placed on a filter above zinc sulphide the rate of solution of zinc sulphide was not greatly increased. Gottschalk and Buehler conclude that the acceleration of the reactions is due to electric currents generated by contact of minerals of different potential. The electric current flows from the mineral having the higher potential, so the one of lower potential will dissolve more rapidly, the one of higher potential being protected from oxidation and solution.

Gottschalk and Buehler arranged several minerals in a series analogous to the electromotive series of the metals, the values having been determined by the use of the Ostwald potentiometer. The results of the experiments are shown below. The force generated while any two of these minerals are immersed in a solution tends to accelerate

¹ Gottschalk, V. H., and Buehler, H. A., Oxidation of sulphides: *Econ. Geology*, vol. 7, 1912, pp. 15-34.

the oxidation and dissolution of that sulphide which stands lower in the series and to retard the oxidation of the one that stands higher. It is noteworthy that the experiments were made with distilled water. The potential varies with the solution, and for some salts the relations are not those indicated in the table.

Potential, in volts, of several sulphides measured in distilled water against copper wire.

Marcasite.....	+0. 37	Chalcocite.....	+0. 14
Argentite.....	+0. 27	Hematite.....	+0. 08 to 0. 26
Cassiterite.....	+0. 27	Cuprite.....	+0. 05
Chalcopyrite.....	+0. 18 to 0. 30	Niccolite.....	+0. 02
Enargite.....	+0. 18 to 0. 23	Domeykite.....	+0. 01
Molybdenite.....	+0. 20	Metallic copper.....	0. 00
Covellite.....	+0. 20	Stibnite.....	-0. 17 to 0. 6
Pyrite.....	+0. 18	Sphalerite.....	-0. 2 to 0. 4
Bornite.....	+0. 17	Corundum.....	-0. 25 to 0. 6
Mixed copper ore.....	+0. 15	Metallic zinc.....	-0. 83
Galena.....	+0. 15		

According to this table marcasite shows the highest electromotive force and corundum shows the lowest for the minerals, the difference being more than 0.6 volt. Metallic zinc shows a negative relation to copper of 0.83 volt, and there is a difference of 1.2 volts between the highest and lowest member of the series.

A piece of pyrite and a piece of galena, each 2 inches long and about 1 inch square, each having copper wire attached near one end, were placed in a small dish containing ordinary distilled water. The wire did not touch the water, nor were the minerals in contact. A circuit formed by placing a galvanometer between the free ends of the wires showed the same difference in potential that is shown in the above table and recorded a current of about 5 microamperes. In the course of a few days, the circuit being maintained, the galena became coated with lead sulphate, while a similar piece of galena, placed in the same solution but not in circuit, remained perfectly bright. The pyrite showed no evidence of oxidation.

Lawson¹ placed a mixture of pulverized chalcocite and porphyry in a burette and passed a 10 per cent solution of ferrous sulphate through it in the presence of air. The chalcocite was dissolved and passed from the burette as copper sulphate (CuSO_4) at a fairly rapid rate.

Winchell² placed crystals of pyrite in a sealed jar in a slightly acid solution, containing sulphur dioxide and a dilute solution of copper sulphate. At the end of three months films of chalcocite were deposited on the pyrite, and its copper content, which at the beginning

¹ Lawson, A. C., The copper deposits of the Robinson mining district, Nevada: Bull. Dept. Geology Univ. California, vol. 4, 1906, p. 833.

² Winchell, H. V., Synthesis of chalcocite and its genesis at Butte, Mont.: Bull. Geol. Soc. America, vol. 14, 1903, pp. 272-275.

was 1.50, had increased to 3.60 per cent. In another jar, with similar reagents except sulphur dioxide, no chalcocite was deposited. Winchell suggests that sulphur dioxide is necessary for the deposition of cuprous sulphide. He infers that the cupric sulphate in solution with sulphur dioxide supplies cuprous ions for the reaction with the pyrite that supplies the sulphur for the chalcocite, the iron going into solution as ferrous salt. He found that iron was dissolved and subsequently precipitated as ferric hydrate.

Recently, in support of Winchell's suggestion, Spencer¹ has discussed the possible reactions involved in chalcocite deposition.

The inference that cuprous ions form in this reaction has not received universal acceptance, because cuprous salts have not been identified in mine waters. Cuprous sulphate is a very unstable compound. It may be held in solution in some substances, but it is stated that when placed in water it quickly becomes cupric sulphate. Recently, however, Wells² has shown that cuprous ions may exist in exceedingly small concentration under conditions nearly similar to those that prevail where sulphate waters attack iron and copper sulphides. Examination of eight mine waters collected by the writer failed, however, to reveal a trace of cuprous salt.

Oxygen tends to delay or to inhibit the precipitation of copper sulphides. Possibly an explanation of the behavior of the two chemical systems above described, one with and the other without sulphide dioxide, lies in the power of sulphur dioxide to remove atmospheric air from the solution. The oxygen would be removed to form sulphuric acid, and copper sulphide would then be more readily precipitated by pyrite. In the jar without sulphur dioxide enough oxygen may have been present to effectively delay precipitation.

Vogt³ pulverized 6 grams each of chalcocite, bornite, pyrrhotite, chalcopyrite, and pyrite and separately treated them in 100 cubic centimeter jars with aqueous solutions containing 30 grams of ferric chloride. After standing several years at about 14° C. they were dissolved in the order named. The filtrates from chalcocite and bornite showed a trace of sulphate, chalcopyrite a stronger trace, and pyrite a still stronger trace. Sulphur separated from the first four minerals and probably also from pyrite. Sulphur did not appear to oxidize to sulphate in the reaction with chalcocite, though oxidation occurred in some degree with pyrite and pyrrhotite.

¹ Spencer, A. C., Chalcocite deposition: Jour. Washington Acad. Sci., vol. 3, 1913, pp. 70-75.

² Wells, R. C., Discussion of paper by F. L. Ransome on "Criteria of downward sulphide enrichment": Econ. Geology, vol. 5, 1910, p. 482.

³ Vogt, J. H. L., Problems in the geology of ore deposits, in Pošepný, Franz, The genesis of ore deposits, 1902, pp. 676-677.

In the table below the solubilities of several anhydrous sulphates are compared.

Anhydrous sulphate held in solution in a liter of water at 18° C.

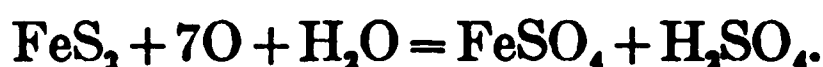
	[After Kohlrausch.]	Grams.
BaSO ₄		0.0023
PbSO ₄.....		.041
CaSO ₄		2.0
Ag ₂ SO ₄		5.5
K ₂ SO ₄		111.1
Na ₂ SO ₄		168.3
MgSO ₄		354.3
ZnSO ₄		531.2

In the table below the solubilities of several hydrated sulphates are compared.¹

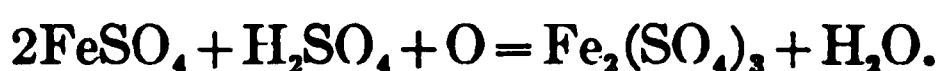
Hydrated sulphates dissolved in a liter of water at about 20° C.

	Grams.
FeSO ₄ .7H ₂ O.....	264.2
CuSO ₄ .5H ₂ O.....	423.3
Al ₂ (SO ₄) ₃ .18H ₂ O (at 0).....	868.5
MgSO ₄ .7H ₂ O.....	1,160.0
ZnSO ₄ .7H ₂ O.....	1,610.0
Na ₂ SO ₄ .10H ₂ O (at 31.25°)	4,800.0

The chemical practice in the leaching process at Rio Tinto, Spain,² is said to be as follows. The ore heaps are built up with open spaces to give ready access of air and water. In the presence of these the following reactions, according to Austin, take place:



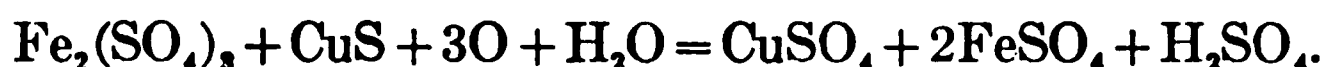
The ferrous sulphate oxidizes to ferric sulphate thus:



The ferric sulphate reacts on chalcocite and changes it to sulphate as follows:



This reaction is relatively rapid, and, accordingly, about half the copper goes into solution in a few months. The covellite molecule remaining is further dissolved according to the following reaction:



This reaction is slow, but in two years, under favorable conditions, 80 per cent of the remaining half of the copper is dissolved. These chemical processes illustrate in a large way the processes of solution of chalcocite under natural conditions.

¹ Data from Comey's and from Seidell's dictionaries of solubilities. I have utilized also Lindgren's compilation, Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 181.

² Austin, L. S., *The metallurgy of the common metals*, 2d ed., San Francisco, 1909, pp. 351-353.

In connection with the processes of solution of copper at Rio Tinto, the following statement by Arthur L. Collins is of interest:

Reactions relied upon for the removal of copper from the zone of weathering, namely, the decomposition of copper sulphides by ferric sulphate, * * * are employed at Rio Tinto on a very large scale in the treatment of copper ore. The liquors from the lixiviation of heap-roasted ore were run over "raw" fine ore, originally to lessen the consumption of iron in the precipitation tanks and to secure a cleaner precipitate. But this was found to be also an efficient method of extracting part of the copper content of raw pyrites, and great heaps of mixed "raw fines" and lixiviated roasted ore, aggregating millions of tons, gradually giving up their copper in solution, largely by means of this reaction, became a feature of the Rio Tinto landscape. The supposed reaction for the reprecipitation of copper in secondary copper ores from cupric sulphate solutions by pyrites can hardly take place under these conditions; it would upset the commercial process.¹

An explanation of the apparent contradiction in the theory of chalcocite enrichment is offered by S. F. Emmons.² He notes that near the surface, where oxidation and leaching take place at Rio Tinto, the air has free access to the ore, whereas air is not admitted to ores that lie at great depths where copper is precipitated.

Copper is precipitated from sulphate solution by alkaline silicates. E. C. Sullivan³ placed finely ground materials—such as orthoclase, albite, amphibole, and clay gouge—in flasks with copper sulphate, silver sulphate, and other salts. They remained several days at room temperature, being occasionally shaken. The solutions were dilute and the precipitation in many of the flasks was nearly complete. Whether contact was maintained for a few hours or a few months made little difference. Analyses of the filtrate before and after the reactions showed that considerable material, especially the alkalies, had been dissolved from the silicate. The filtrate from 25 grams of powdered orthoclase with 40 cubic centimeters 0.1 normal sulphuric acid (2.50 millimols) gave the following results:⁴

Orthoclase and sulphuric acid: content of 40 cm³.

Constituent.	Grams.	Millimols.
SiO ₂	0.0242	.....
Al ₂ O ₃.....	.0313	^a 0.92
CaO.....	Undet.	.....
MgO.....	.0010	.03
K ₂ O.....	.0556	.59
Na ₂ O.....	.0108	.17
Total.....	.1229	1.71
Total in 50 cm ³.....	.1536	2.14

^a This is the number of divalent millimols to which 0.0313 gram alumina is equivalent.

¹ Collins, A. L., in Pošepný, Franz, The genesis of ore deposits, 1902, p. 621.
² Emmons, S. F., *Idem*, p. 756.
³ Sullivan, E. C., The interaction between minerals and water solutions, with special reference to geologic phenomena: Bull. U. S. Geol. Survey No. 312, 1907, pp. 37-64.
⁴ *Idem*, p. 50.

The acid has dissolved somewhat less than its own equivalent of bases from the orthoclase. No change in the concentration of the sulphate radicle could be detected.

Albite ($\text{NaAlSi}_3\text{O}_8$) in contact over night with cupric sulphate solution gave the following results:

Experiment with albite and cupric sulphate.

Constituent.	Grams.	Millimols.
Copper in 50 cm ³ :		
Originally.....	0.1266	1.99
Finally.....	.0343	.54
Loss.....	.0923	1.45
Content of 38.34 cm ³ :		
SiO ₂.....	.0046	.....
Al ₂ O ₃.....	.0020	.06
CaO.....	.0107	.19
Na ₂ O.....	^a .0516	.83
Total.....	.0689	1.08
Content of 50 cm ³.....	.0698	1.41

^a Including a little MgO and K₂O.

Twenty-five grams powdered orthoclase were placed in contact for two days with 50 cubic centimeters of silver sulphate solution. The silver was almost completely precipitated.

Experiment with orthoclase and silver sulphate.

Constituent.	Grams.	Milli-equivalents.
Silver in 50 cm ³ :		
Originally.....	0.1066	0.98
Finally.....	.0039	.04
Loss.....	.1027	.94
Content of 30.27 cm ³ :		
SiO ₂ , Fe ₂ O ₃ , etc.....	.0007	.....
CaO.....	.0001	.....
MgO.....	.0004	.02
K ₂ O.....	.0170	.36
Na ₂ O.....	.0073	.23
Total.....	.0255	.61
Total in 50 cm ³.....	.0421	1.01

Experiments by Sullivan on shale from Morenci, Ariz., are described by Lindgren¹ as follows:

Fifty grams of shale finely ground in agate mortar were placed in 100 cubic centimeters of solution of cupric sulphate containing 0.0025 gram of copper per cubic centimeter. After standing for four days, with occasional shaking, the solution contained but 5 per cent of that amount of copper. A solution of the same strength had lost all its copper after four months' contact with shale. A concentrated solution with original content of 0.7645 gram copper per cubic centimeter had but 0.7058 gram

¹ Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 192.

copper per cubic centimeter after a few days' contact, 100 cubic centimeters of solution thus giving up nearly 0.6 gram copper (0.75 g. cupric oxide, CuO) to 50 grams shale.

A certain amount of acid radicle is also taken from the solution by the shale. This loss in one experiment with the dilute copper sulphate mentioned was something over 10 per cent of the total SO_4 .

The shale in turn gives off a part of its constituents to the solution, about 0.2 gram having been found in 100 cubic centimeters after treatment with the dilute copper-sulphate solution. This is 0.4 per cent of the 50 grams shale taken. Of this dissolved matter, mostly present as sulphate, one-third to one-half was potassium oxide, most of the remainder being magnesium oxide and calcium oxide, with sodium oxide, manganese oxide, ferric oxide, and silica in smaller quantities.

The acidity of the solution was not increased by removal of copper, analysis showing that copper precipitated in excess of that equivalent to the acid radicle removed was replaced in solution by other bases as sulphates.

Reactions of this character are probably at some places important processes in the enrichment of ore bodies, for the essential conditions of the experiments commonly exist in nature. The neutralization of the acid solutions by the alkaline silicates permits also such reactions as are favored by a neutral environment.

In some silver and copper mines clay gouge and highly altered material carry valuable minerals. This altered material may have been produced by the attrition of rock originally metalliferous, but the experiments described above suggest processes by which it may have been enriched. The results of experiments showing the extent to which these reactions may go on when sulphides also are present are not available.

According to Stephen H. Emmens,¹ hydrogen sulphide and sulphur dioxide form with sulphur as intermediate steps in the oxidation of pyrite. These compounds, however, will oxidize where oxygen is in excess, or in the absence of water pressure they can readily escape; thus hydrogen sulphide would have but little effect in precipitating the metals in the oxidizing zone.

The statement of Emmens that hydrogen sulphide is formed in the oxidation of sulphides was made as early as 1892, but it was not supported by a record of experiments and it has not received the attention that it probably deserves. Buehler and Gottschalk showed that pure water does not generate hydrogen sulphide in the presence of oxygen with sulphides, but it is formed on contact with some sulphides and weak sulphuric acid.

The crystallized and the freshly precipitated sulphides of a metal may show considerable difference in solubility in water, as is indicated by the table below, which gives the results of a number of determinations by Weigel,² who used a sensitive apparatus for measuring these very low solubilities. Weigel showed also that the amount

¹ Emmens, S. H., The chemistry of gossan: Eng. and Min. Jour., vol. 54, 1892, pp. 582-583.

² Weigel, Oskar, Die Löslichkeit von Schwermetallsulfiden in reinem Wasser: Zeitschr. phys. Chemie, vol. 58, 1907, pp. 293-300.

of lead sulphide dissolved in water increases for a short period and then decreases, owing probably to the precipitation from the solution of crystallized galena, or some dense form which is less soluble than the freshly precipitated sulphide.

Solubility of the sulphides of the heavy metals in distilled water at 18° C.

[Mols $\times 10^{-6}$ per liter.]

Crystallized.		Freshly precipitated (probably amorphous).	
MnS.....	54. 5	MnS.....	71. 60
Pyrrhotite.....	53. 6	ZnS.....	70. 60
Pyrite (Freiberg).....	48. 89	FeS.....	70. 1
Pyrite (artificial).....	40. 84	CoS.....	41. 62
Wurtzite (artificial).....	28. 82	NiS.....	39. 87
Millerite (artificial).....	16. 29	CdS.....	9. 00
Greenockite (artificial).....	8. 99	Sb ₂ S ₃	5. 2
Zinc blende (Santander).....	6. 55	PbS.....	3. 6
Zinc blende (artificial).....	6. 63	CuS.....	3. 51
Cu ₂ S.....	3. 1	As ₂ S ₃	2. 1
Galena (Freiberg).....	1. 21	Ag ₂ S.....	. 552
Galena (artificial).....	1. 21	Bi ₂ S ₃.....	. 35
Galena (from precipitated PbS).....	1. 18	HgS.....	. 054
SnS ₂	1. 13		
Ag ₂ S.....	. 5522		
SnS (crystallized).....	. 14		

Schuermann,¹ after extensive experimentation, established a series in which the sulphides of any one of the metals thereof will be precipitated at the expense of any sulphide lower in the series. He used 50 cubic centimeters, of about 0.1 formula weight, of solutions of the salts noted below with 100 cubic centimeters of water and introduced small amounts of metallic sulphides.

Amounts of various salts used in Schuermann's experiments.

	Grams per liter.
CuSO ₄ .5H ₂ O	24. 880
Pb(NO ₃) ₂	33. 018
ZnSO ₄ .7H ₂ O	28. 642
NiSO ₄ .7H ₂ O	28. 014
Co(NO ₃) ₂ .6H ₂ O.....	29. 014
FeSO ₄ .7H ₂ O.....	27. 742
HgCl ₂	27. 054
CdSO ₄ . $\frac{1}{2}$ H ₂ O.....	25. 541
BiO ₂ .H ₂ (NO ₃).....	30. 311
MnSO ₄ .5H ₂ O	24. 042
AgNO ₃	16. 955
SnCl ₂ .2H ₂ O	22. 406
PdCl ₂	17. 694
$\frac{1}{2}$ As ₂ O ₃	9. 884
C ₄ H ₄ O ₆ $\frac{SbO}{K}$. $\frac{1}{2}$ H ₂ O.....	33. 119

The sulphides were placed in 150 cubic centimeter flasks that were closed with a Bunsen valve to allow steam to escape and to prevent access of air. On the application of heat the metal in solution as

¹ Schuermann, Ernst, Ueber die Verwandtschaft der Schwermetalle zum Schwefel: Liebig's Ann. der Chemie, vol. 249, 1888, p. 326.

sulphate, as chloride, or as nitrate was precipitated as sulphide, and the metal of the introduced sulphide simultaneously went into solution. In general, the attack was continued for several hours. His series is as follows: Palladium, quicksilver, silver, copper, bismuth, cadmium, lead, zinc, nickel, cobalt, iron, thallium, and manganese. Under the conditions named any metal in solution will, according to Schuermann, be precipitated as sulphide if in contact with a metal lower in the series and the metal lower in the series will simultaneously go into solution. As a rule the reaction is the more nearly complete the farther apart the two metals are in the series.

In a series which he regards as showing the "relative affinity" of the heavy metals for sulphur Schuermann includes antimony, arsenic, and tin. This series is palladium, mercury, silver, copper, bismuth, cadmium, antimony, tin, lead, zinc, nickel, cobalt, iron, arsenic, thallium, and manganese. Those last named have the least affinity.

Schuermann's results have been widely applied. The term "chemical affinity" is a convenient one but is used in absence of more definite information to express a relation, not chemical constants. As pointed out by Wells, the principal results of Schuermann's experiments may be regarded as reactions establishing chemical equilibria, the salts being fixed in order of their solubilities under the conditions of the experiments. The positions of the commoner metals in the Schuermann series agree fairly well with the solubilities of the sulphides determined by Weigel, and the metals which replace those lower in the series generally have lower solubilities than those which are replaced. As shown in the table that follows there are, however, several discrepancies between the Schuermann series and Weigel's table.

If ammonium sulphide is added to a solution in which the metals are dissolved (in equal molar concentration) those which have the lowest solubilities should be precipitated first. Under similar conditions and with equal molar concentrations the metals would be precipitated by ammonium sulphide approximately but not exactly in the order indicated in the Schuermann series. This order of precipitation would hold, however, for the sulphides of the most common metals and for those which are assumed to be most important in problems of sulphide enrichment.

In the table below Schuermann's series is compared with a series showing the solubilities of the metallic sulphides as determined by Weigel, the numbers in parentheses indicating the order of (molar) solubility. In Schuermann's series the metals are arranged in the order of their decrease of "affinity for sulphur."¹ In Weigel's series the order of solubility of the freshly precipitated metallic sul-

¹ Schuermann, Ernst, Ueber die Verwandtschaft der Schwermetalle zum Schwefel: *Liebig's Ann. der Chemie*, vol. 249, 1888, p. 326. Emmons, S. F., The secondary enrichment of ore deposits: *Trans. Am. Inst. Min. Eng.*, vol. 30, 1901, p. 212. Weed, W. H., The enrichment of gold and silver veins: *Trans. Am. Inst. Min. Eng.*, vol. 30, 1901, p. 428; The affinity of metals for sulphur: *Eng. and Min. Jour.*, vol. 50, 1890, p. 484; Review of lecture by Watson Smith, on Schuermann's reactions: *Jour. Soc. Chem. Ind.*, vol. 11, 1892, pp. 860-871.

phides is expressed in mols per liter; ¹ to each amount stated should be applied the factor $\times 10^{-6}$.

Comparison of Schuermann's and Weigel's series.

Schuermann's series.	Weigel's series.	
(1) Hg.	(1) HgS.....	0.054
(2) Ag.	(3) Ag ₂ S.....	.552
(3) Cu.	(4) CuS.....	3.51
(4) Bi.	(2) Bi ₂ S ₃.....	.35
(5) Cd.	(6) CdS.....	9.0
(6) Pb.	(5) PbS.....	3.6
(7) Zn.	(10) ZnS.....	70.6
(8) Ni.	(7) NiS.....	39.81
(9) Co.	(8) CoS.....	41.62
(10) Fe.	(9) FeS.....	70.1
(11) Mn.	(11) MnS.....	71.6

Hydrogen sulphide is made in the chemical laboratory by treating artificial ferrous sulphide with acid. The generation of hydrogen sulphide is almost instantaneous. As recently shown by Allen, pyrrhotite is in reality a solid solution of ferrous sulphide (FeS) and sulphur. Both pyrrhotite and zinc blende dissolve in acid with noticeable evolution of hydrogen sulphide, whereas pyrite and chalcopyrite are almost insoluble in sulphuric or in hydrochloric acid. They are readily decomposed, however, in nitric, an oxidizing acid.

Several experiments were made by R. C. Wells to ascertain the rates at which hydrogen sulphide is generated by the action of cold dilute acid waters on sulphides of the metals. The ores, obtained from the Smithsonian Institution through the courtesy of Dr. J. E. Pogue, were pyrite from Leadville, Colo.; chalcopyrite from the Cactus mine, Utah; sphalerite from Webb City, Mo.; pyrrhotite from Ely, Vt.; and galena from the Motley mine, Cartersville, Mo. All these specimens appeared to be pure. They were powdered, washed with hydrochloric acid, alcohol, and ether, and sifted, the material passing a 200-mesh sieve and that held on an 80-mesh sieve being rejected. Thus the material used was free from fine dust and lumps.

In preliminary experiments the minerals were used in quantities proportional to their densities, thus insuring approximately equal surfaces. Portions of the minerals placed in flasks and covered with 0.1 normal sulphuric acid showed no visible change until a week had elapsed, when flasks containing pyrrhotite began to show a precipitate of basic ferric sulphate. No regularity was found in the variation in the acidity of the solutions on account of the simultaneous consumption and production of acid with the different minerals.

The five minerals were further exposed overnight to 0.057 normal sulphuric acid. The resulting solutions were titrated with iodine solution to ascertain the amount of hydrogen sulphide generated, the iodine solution used being, for pyrrhotite, 28.5 cubic centimeters; for sphalerite, 1.05 cubic centimeters; for galena, 0.40 cubic centimeter; for chalcopyrite, 0.29 cubic centimeter; for pyrite, 0.28 cubic centimeter.

¹ Weigel, Oskar, *Zeitschr. phys. chemie*, vol. 58, p. 293.

A set of experiments exactly similar to the above was made, the resulting solutions being titrated with potassium permanganate. The consumption of the salt with the solutions from pyrrhotite greatly exceeded the consumption with those from any other mineral.

In another series of experiments the hydrogen sulphide generated by the action of cold dilute acid on pyrrhotite, on sphalerite, and on galena was determined qualitatively by lead acetate paper. There was no proof that hydrogen sulphide was formed with either pyrite or chalcopyrite, and the very small quantities indicated above (0.28 cubic centimeter for pyrite and 0.29 cubic centimeter for chalcopyrite) are not regarded by Mr. Wells as proof that hydrogen sulphide is formed by the action of acid on pyrite and chalcopyrite. The slight reduction of the iodine solution may represent a correction for the end point of the titration.

COMPOSITION OF MINE WATERS.

ANALYSES.

The following tables show the results of analyses of 37 samples of water taken from mines containing deposits of sulphide ore:

Analyses of mine waters.
Waters of copper mines.
[Parts per million.]

	1	2	3	4	5	6	7	8	9
SO ₄	406.5	544.7	90.6	593.4	71,053.3	2,672.0	492.1	6,664.0	2,068.0
Cl.....	6.8	118.5	11.8	842.8	17.7	13.0	95.7	.1	2.2
CO ₂	13.2	Tr.	.....	.....	.....	.....	.....	.....	.....
PO ₄	Tr.	Tr.	Tr.	Tr.	1.5	Tr.	.....	.....	.....
B ₂ O ₃.....	.....	.....	.....	.....	.....	Tr.	.....	.....	.....
Br.....	.....	.....	.....	.....	.....	Tr.	.....	.....	.....
F.....	.....	.....	.....	.....	.....	Tr.	.....	.....	.....
SiO ₂	23.2	27.2	36.1	29.5	67.4	47.7	94.8	55.6	78.9
K.....	7.1	30.5	3.5	11.4	6.8	18.1	27.9	19.8	7.8
Na.....	16.2	176.9	11.1	82.8	41.7	39.6	33.0	23.4	5.9
Li.....	Tr.	.....	.....	.....	Tr.	.....	.....	.....	.....
Ca.....	151.2	92.7	49.0	512.1	307.7	132.5	105.8	67.6	238.0
Mg.....	28.2	17.9	10.3	102.6	149.2	61.6	25.5	40.6	63.3
Al.....	0.0	.....	.....	.....	85.2	83.5	.....	433.0	165.0
Mn.....	.5	Tr.	2.5	1.4	13.2	12.0	.....	.2	.3
Ni.....	.....	.....	.....	.....	3.5	.....	.....	.....	.....
Co.....	.....	.....	.....	.....	4.6	.5	.....	.....	.....
Cu.....	Tr.	.4	.....	.....	45,633.2	59.1	.....	312.1	40.8
Zn.....	.3	1.8	1.9	0.0	411.2	852.0	.....	199.8	54.3
Cd.....	.....	.....	.....	.....	.....	41.1	.....	.....	.....
Fe''.....	1.8	1.4	.9	.4	.....	.....	58.1	2,178.0	1.3
Fe'''.....	.....	.....	.....	.....	49.8	159.8	1.9	0.0	186.3
Acidity: H ₂ SO ₄ ...	Alk.	Alk.	Alk.	Alk.	.....	.....	.....	129.6	406.5

1. Green Mountain mine, Butte, Mont., 2,200-foot level in fissure in "granite," remote from known veins. Crosscut opened day before sample was taken. W. F. Hillebrand, analyst. Weed, W. H., Geology and ore deposits of the Butte district, Montana: Prof. Paper U. S. Geol. Survey No. 74, 1912, p. 101.
2. Glengarry mine, Butte, Mont., 220-foot crosscut south. Very slightly alkaline. Black deposit containing FeS, much free sulphur, and probably ZnS. W. F. Hillebrand, analyst. Weed, idem.
3. Anaconda mine, Butte, Mont., 800 feet west. Very faintly alkaline; deposits iron and manganese. W. F. Hillebrand, analyst. Weed, idem.
4. Gagnon mine, Butte, Mont., 1,125 feet from shaft. Very faintly alkaline; deposits iron. Weed, idem.
5. Mountain View mine, Butte, Mont., second level. W. F. Hillebrand, analyst. Clarke, F. W., The date of geochemistry: Bull. U. S. Geol. Survey No. 330, 1908, p. 546; also Weed, loc. cit.
6. St. Lawrence mine, Butte, Mont. W. F. Hillebrand, analyst. Clarke, loc. cit.; also Weed, loc. cit.
7. Ruth mine, Robinson mining district, Nevada, bottom of inclined shaft. H. E. Miller, analyst. Lawson, A. C., The copper deposits of the Robinson mining district, Nevada: Bull. Dept. Geology Univ. California, vol. 4, 1906, p. 332.
8. Burra Burra mine, Ducktown, Tenn., first level below black copper workings. R. C. Wells, analyst. Emmons, W. H., and Laney, F. B., Preliminary report on the mineral deposits of Ducktown, Tenn.: Bull. U. S. Geol. Survey No. 470, 1911, pp. 171-172.
9. East Tennessee mine, Ducktown, Tenn., 30-foot fathom level. R. C. Wells, analyst. Emmons and Laney, idem.

Analyses of mine waters—Continued.
Waters of copper mines—Continued.

	10	11	12	13	14	15	16	17	18
SO ₄	444.0	416.4	415.8	476.8	5,064	1,419	4,457	3,898	1,335
Cl.....	.7	.6	.7	.4	Undet.	18	22	Undet.	.....
CO ₂.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
PO ₄.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
B ₂ O ₃.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Br.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
F.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
SiO ₂	20.6	19.1	37.0	49.9	76	28	56	40	20
K.....	3.2	2.8	2.7	2.2	} Undet.	a 170	a 198	a 97	a 14
Na.....	3.1	3.0	5.2	5.5					
Li.....	.....	.....	.....	.....	
Ca.....	18.1	18.4	19.7	30.4	436	319	753	239	277
Mg.....	12.2	11.5	5.2	6.2	61	36	86	82	54
Al.....	40.1	46.5	14.5	19.1	Undet.	16	22	44	9
Mn.....	.3	.9	.2	.1	236	37	153	150	45
Ni.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Co.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Cu.....	12.8	12.0	28.1	11.0	1,659	.....	60	122	28
Zn.....	6.1	4.2	2.4	2.9	Undet.	73	252	190	52
Cd.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Fe'.....	Tr.	Tr.	71.4	89.2	305	76	524	799	149
Fe''.....	29.9	31.3	20.3	55.9	.....	.....	.....	.....	24
Acidity: H ₂ SO ₄ ...	108.2	115.1	210.2	97.5	970	Nil.	Nil.	Nil.	Nil.

a Calculated as K₂O+Na₂O.

10. No. 20 shaft (top), Ducktown, Tenn. Emmons and Laney, unpublished manuscript.
11. No. 20 shaft (bottom), Ducktown, Tenn. Emmons and Laney, idem.
12. Callaway shaft, Ducktown, Tenn., at water level. R. C. Wells, analyst. Emmons and Laney, Preliminary report on the mineral deposits of Ducktown, Tenn.: Bull. U. S. Geol. Survey No. 470, 1911, pp. 171-172.
13. Callaway shaft, Ducktown, Tenn., 37 feet below water level. R. C. Wells, analyst. Emmons and Laney, idem.
14. Capote mine, Cananea, Mexico, 300-foot level. G. W. Hawley (chief chemist Cananea Consolidated Copper Company), analyst. Analyses 14 to 17 obtained through the courtesy of Mr. D. P. Hynes.
15. Capote mine, Cananea, Mexico, 400-foot level. G. W. Hawley, analyst.
16. Capote mine, Cananea, Mexico, 900-foot level. G. W. Hawley, analyst.
17. Capote mine, Cananea, Mexico, water pumped from mine. G. W. Hawley, analyst.
18. Capote, Puertacitas, Cananea-Duluth, and Democratic mines, Cananea, Mexico, water used at concentrator at Cananea. Circulates at concentrator in contact with ore and air. G. W. Hawley, analyst.

Analyses of mine waters—Continued.

Waters of gold, silver, and gold and silver mines.

	19	20	21	22	23	24	25	26	27	28
SO ₄	43.20	161.70	380.38	474.00	209,100.00	173.40	272.30	160.00	7.70	7.80
Cl.....	7.90	186.40	1.27	19.00	127.60	.52	13.77	16.82	3.16	3.10
CO ₂	110.50	1,513.44	115.03	20.45	.....	47.71	241.39	194.70	141.80	146.60
NO ₂.....	.....	1.60	.....	.....	.....	.....	.....	.....	.....	.....
PO ₄	Tr.	Tr.	.....	.....	.....	.....	.....	.....	.....	.....
S.....	.....	.....	.....	.....	.....	.....	.....	.....	1.10	.....
SiO ₂	25.90	24.42	30.50	133.40	616.00	37.86	59.96	68.92	32.70	41.40
K.....	10.60	198.00	8.39	53.40	.....	62.26	80.90	254.10	1.00	1.60
Na.....	36.40	719.45	57.13	132.00	535.00	.27	6.86	7.84	13.49	13.70
Li.....	Tr.	2.85	.....	.....	.....	.....	.....	.....	.....	.....
Ca.....	37.40	146.41	148.10	100.10	1,286.00	72.37	113.70	84.08	33.60	44.36
Sr.....	.....	1.95	.....	.....	.....	.....	.....	.....	.....	.....
Mg.....	12.25	177.67	154.03	5.88	6,590.00	.....	.....	.....	5.70	3.35
Al.....	.40	1.06	.....	1.37	9,670.00	.....	.....	.....	.....	.....
Mn.....	.80	.57	.....	.....	885.10	.....	.....	.....	.27	1.90
Ni.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Co.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Cu.....	Tr.	.02	.....	.....	147.50	.....	.....	.....	.....	.....
Zn.....	.20	.34	.....	.....	.....	.....	.....	.....	.....	.....
Pb.....	Tr.	1.35	.....	.....	.....	.....	.....	.....	Tr.	Tr.?
Fe''.....	} .70	3.50	{.....	6.33	5,025.00	Tr.	Tr.	Tr.	.....	.....
Fe'''.....						Tr.	Tr.	Tr.	.....	.....
H (bicarbonates).....	.....	.....	.....	.....	.....	.....	.....	.....	4.60	4.70
H (acids).....	.....	.....	.....	.....	2,575.00	.....	.....	.....	Alk.	Alk.
Fe ₂ O ₃}.....	.....	.....	.....	.....	.....	.....	.....	.....	} 4.20	1.80
Al ₂ O ₃.....	.....	.....	.....	.....	.....	.....	.....	.....
CO ₂	37.20	1,418.61	.....	.....	.....	.....	.....	.....	.....	.....

19. Geyser mine, Custer County, Colo., 500-foot level. W. F. Hillebrand, analyst. Emmons, S. F., The mines of Custer County, Colo.: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 461.

20. Geyser mine, Custer County, Colo., 2,000-foot level. W. F. Hillebrand, analyst. Emmons, S. F., op. cit., p. 462.

21. Savage mine (Comstock lode), Storey County, Nev., 600-foot level.

22. C. & C. shaft (Comstock lode), Storey County, Nev., 2,250-foot level. N. E. Wilson, analyst. Reid, J. A., The structure and genesis of the Comstock lode: Bull. Dept. Geology Univ. California, vol. 4, 1906, p. 189.

23. Central tunnel (Comstock lode), Storey County, Nev., vadose water. N. E. Wilson, analyst. Reid, J. A., loc. cit., p. 192.

24. Gould & Curry mine (Comstock lode), Storey County, Nev., 1,700-foot level.

25. Hale & Norcross tunnel section (Comstock lode), Storey County, Nev.

26. Gould & Curry mine (Comstock lode), Storey County, Nev., 1,800-foot level.

27. Federal Loan mine, Nevada City, Cal., 400-foot level. W. F. Hillebrand, analyst. Lindgren, Waldemar, The gold-quartz veins of Nevada City and Grass Valley, California: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 121.

28. Black Prince mine, Nevada City, Cal., 400-foot level. W. F. Hillebrand, analyst. Lindgren, idem.

Analyses of mine waters—Continued.

Waters of gold, silver, and gold and silver mines—Continued.

	29	30	31	32	33	34	35	36	37
SO ₄	258.40	26.55	280.10	124.80	60.12	104.4	2,039.51	327.2	67.2
Cl.....	Tr.	Tr.	Tr.	12.40	Tr.	1.6	8.16	35.6	15
CO ₂					78.3	92.4		87.9	130
NO ₂								Tr.	
PO ₄									
S.....									
SiO ₂	2.10	8.00	8.80	18.00	32.25	23.2	43.80	64.8	55.8
K.....					2.41	3.5	70	3.4	5.0
Na.....					28.52	7.5	106.27	148.8	30.1
Li.....									
Ca.....	90.76	72.48	106.20	46.40	17.36	46.2	187.15	68.8	39.1
Sr.....									
Mg.....	13.08	14.90	17.14	14.50	1.30	7.3	93.50	6.3	6.7
Al.....	1.49	.37	1.49				3.12		
Mn.....	4.74	4.12	1.88		.25	3.2	155.58	.7	.8
Ni.....	Tr.	Tr.	Tr.						
Co.....	Tr.	Tr.	Tr.						
Cu.....							77.05		
Zn.....	2.82	47.40	18.88	8.90			49.66	Tr.	
Pb.....							3.44		
Fe''.....				6.60	1.47	.85	164.82		.4
Fe'''.....	4.74	6.30	4.69					.7	
H (bicar-									
bonates).									
H (acids).....					Alk.	Alk.			
Fe ₂ O ₃									
Al ₂ O ₃									
CO ₂					61.53	72.60			

29-32. Roths  nberger Stolln, Freiberg, Germany. A. Frenzel, analyst. Beck, Richard, The nature of ore deposits (translated by W. H. Weed), vol. 2, 1905, p. 377.
33. Bachelor mine, Creede, Colo. Iron includes some aluminum. Water is alkaline. Chase Palmer, analyst.
34. Solomon mine, Creede, Colo. Iron includes some aluminum. Water is alkaline. Chase Palmer, analyst.
35. Stanley mine, Idaho Springs, Colo. L. J. W. Jones, analyst. Jones, L. J. W., Ferric sulphate in mine waters and its action on metals: Proc. Colorado Sci. Soc., vol. 6, 1897-1900, p. 48.
36. Mispah mine, Tonopah, Nev., from bore hole 2,316 feet deep. Bicarbonates were reduced to normal carbonates. R. C. Wells, analyst.
37. Nettle mine, Butte, Mont., 300-foot level. W. F. Hillebrand, analyst. Weed, W. H., Geology and ore deposits of the Butte district, Montana: Prof. Paper U. S. Geol. Survey No. 74, 1912, p. 101.

DISCUSSION OF ANALYSES.

MINES REPRESENTED.

Of the foregoing analyses of 37 samples of water taken from mines containing sulphide deposits, samples 1 to 18 were taken from copper mines and samples 19 to 37 from gold, silver, and gold-silver mines. The tables include almost all the available nearly complete analyses of waters from sulphide deposits in noncalcareous rocks. Among those not included in the table are several analyses of waters from the district in southeastern Missouri containing disseminated lead deposits, discussed by Buckley,¹ and some analyses of waters from the Granby district and from Joplin, in southwestern Missouri. A number of partial analyses of waters from gold mines of Australia and New Zealand are reported by Don,² and several analyses of

¹ Buckley, E. R., Geology of the disseminated lead deposits of St. Francis and Washington counties: Missouri Bur. Geology and Mines, vol. 9, pt. 1, 1908, pp. 99, 171, 249.
² Don, J. R., The genesis of certain auriferous lodes: Trans. Am. Inst. Min. Eng., vol. 27 1898 p. 654.

waters of the Homestake mine, Lead, S. Dak., have recently been published by Sharwood.¹ Analyses of waters from the Lake Superior copper mines, reported by Lane,² have not been included in the tables, for these are chloride waters and their discussion would be irrelevant to the subject of sulphide enrichment.

Five mines are represented by two or more analyses. More extended series of analyses of waters taken at different depths from the same body of water would be very useful in investigations made to determine the acidity and the state of oxidation of waters as related to depth. The first work of this character was done by Lepsius,³ who showed that the oxygen content of waters taken from bore holes decreases with increase of depth. A series of samples (Nos. 14 to 17) from the different levels of the Capote mine, Cananea, Sonora, analyzed under the direction of G. W. Hawley, chief chemist of the Cananea Consolidated Copper Co., is especially valuable. Samples 12 and 13 were obtained from the Callaway shaft at Ducktown, Tenn.; sample 12 was taken from the top of the water level in this shaft, and sample 13 was taken 37 feet below. To obtain this sample a special device was arranged by Mr. Laney and myself for subaqueous filtration. This device consisted of a crate holding two 1-gallon bottles, below which was attached a heavy weight to sink the unfilled bottles; below this was attached, with a short rope, a second weight for sounding. Each bottle was equipped with a small cylindrical filter tube charged with asbestos wool. A perforated porcelain disk was placed below and another above the wool to equalize pressure. The filter tube extended nearly to the bottom of the bottle to prevent air from coming into contact with the water dropping into the bottles. Each stopper was fitted with a glass exhaust tube extending from the top of the bottle to a point above the filter, and the upper end of each tube was fitted with a valve which let out air but prevented any intake of water. Rubber sheeting was fastened over the filter to prevent premature entry of waters and this was removed by means of a strong cord passed to the surface. The bottles were lowered slowly to prevent the stirring of the water in the shaft.

Many of the samples were taken from small bodies of water standing in mines. The water in such bodies is generally more concentrated than the average water of the mines and is probably not typical underground mine water. Samples 8, 9, 10, 11, 12, 13, 22, 27, 28,

¹ Sharwood, W. J., Analyses of some rocks and minerals from the Homestake mine, Lead, S. Dak.: *Econ. Geology*, vol. 6, 1911, p. 742.

² Lane, A. C., Mine waters: *Proc. Lake Superior Min. Inst.*, vol. 13, 1908, pp. 63-152; *Michigan iron mines and their mine waters*: *Jour. Canadian Min. Inst.*, vol. 12, 1910, p. 124.

³ Lepsius, B., Ueber die Abnahme de gelösten Sauerstoffs in Grundwasser und einen einfachen Apparat zur Entnahme von Tiefproben in Bohrlöchern: *Ber. Deutsch. chem. Gesell.*, vol. 18, pt. 2, 1885, pp. 2487-2490.

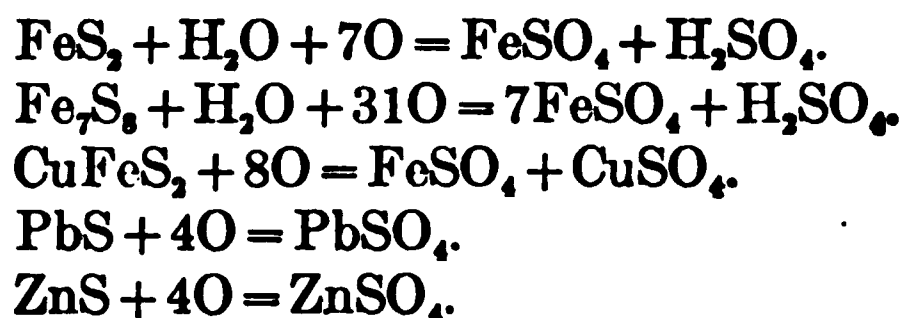
33, 34, 36, and probably several others were taken from underground streams or rills or from large bodies of standing water.

The composition of mine water, especially that in the upper part of a deposit, is changed by the opening of the mine, by which, doubtless, the water is more highly oxidized and probably its acidity is increased. The addition of artificial water channels and the depression of the ground-water level by pumping produces mixtures of water from several levels and increases the rate of the underground circulation. This increase tends to dilute the waters; but, on the other hand, the downward change to a more highly oxidized and therefore a more highly acid condition will render the solutions more active solvents and tend to increase the concentration of metals they contain. Which set of processes predominates can not be shown, but the analyses represent only qualitatively the character of the solutions by which alterations of sulphide ores are brought about. Many of the analyses are not complete, and some analysts do not state whether certain elements were looked for. Some of the averages are therefore only rude approximations.

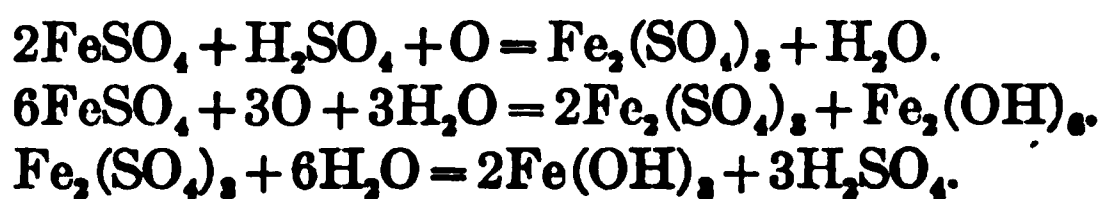
In the work of recalculating these analyses to the ionic form of statement I have had assistance from Messrs. H. K. Shearer, N. Sankowsky, and Clarence Russell.

CHEMICAL CHANGES INDICATED.

Sulphates and sulphuric acid.—Sulphides exposed to air and water are changed to sulphates and to sulphuric acid. The iron minerals are the more important sources of sulphuric acid because some of them contain more sulphur than that necessary to balance iron when iron sulphate forms and because iron sulphate in the presence of oxygen forms the ferric salt, which hydrolyzes readily, giving basic ferric sulphate and ultimately limonite. Galena and zinc blende may oxidize to sulphates without liberating acid. The following equations, which represent certain stages in the reactions, illustrate this principle:



The oxidation of ferrous sulphate to ferric salt and the hydrolyzation of ferric sulphate take place very readily in the presence of oxygen.



All the waters from copper mines (1-18) are sulphate solutions. Carbonates are determined in only one of these—No. 1, which was taken at some distance from any known ore body. The combined acid radicles of several are, however, insufficient to balance the positive ions—a fact that suggests the probability that some of the metals are balanced by carbon dioxide or by ions containing carbon dioxide. The average sulphate (SO_4) of 18 samples of water from copper mines is 5,695.3 parts per million. This figure is increased greatly by sample 5, an exceptionally strong sulphate solution. The average sulphate of the 17 other samples is 1,850.4 parts per million. The average sulphate of 19 samples from gold and silver mines is 11,266.8 parts per million; if the sample of concentrated water (No. 23) from the Comstock lode is eliminated the average of 18 samples is 276.04. In seven of the waters from copper mines the acidity has been determined, the average being 291 parts per million, calculated as sulphuric acid (H_2SO_4). Samples 8 and 9 show appreciable acidity, notwithstanding a deficiency of sulphate ions to balance the metals. In at least 12 samples there is no free acid. At least eight samples from copper and precious-metal mines (1, 2, 3, 4, 27, 28, 33, 34) are alkaline.

Chlorides.—The salt (NaCl) in sedimentary rocks may be dissolved by ground water, and in some places it is a source of commercial supply. From the available analyses it appears that in many regions the amount of salt in such rocks is small. The chlorine content of composite samples of 78 shales and 253 sandstones is only a trace, and an analysis of a composite of 345 limestones shows only 0.02 per cent.¹ A few rock-making minerals, such as chlorapatite, scapolite, haüyne, and nosean, contain combined chlorine; but all of these except apatite occur mainly in rocks of very rare types. In some rocks chlorine is present probably as sodium chloride in the solid particles contained in fluid inclusions.

Apatite, though widespread in igneous rocks, is a very stable mineral and consequently can not be regarded as an important source of chlorine, although it may afford small amounts when exposed to favorable conditions of weathering. The average chlorine content of igneous rocks, according to F. W. Clarke, is 0.06 per cent.

Chlorine is present in nearly all natural waters, which derive it from fine salt or salt water from the sea or other bodies of salt water. The fine salt is carried by the wind and precipitated with rain.² The amount of chlorine in bodies of natural water varies with remarkable constancy with variations in the distance of the bodies from the shore. Several determinations of water from bodies very near the seashore

¹Clarke, F. W., The data of geochemistry, 2d ed.: Bull. U. S. Geol. Survey No. 491, 1911, p. 28.

²Jackson, D. D., The normal distribution of chlorine in the natural waters of New York and New England: Water-Supply Paper U. S. Geol. Survey No. 144, 1905.

show 10 to 30 parts of chlorine per million; in bodies a few miles away it is generally about 6 parts per million; in bodies 50 miles from shore it is generally less than 1 part per million.

In arid countries dust containing salt doubtless contributes chlorine to mine waters. Penrose,¹ discussing the distribution of the chloride ores, pointed out long ago that these minerals form most abundantly in undrained areas.

The average chlorine content of the 18 analyses of waters from copper mines is 63.9 parts per million. In three of these chlorine is not reported, but in two of the three it was not looked for. The average of the 15 samples is 76.7. The samples from gold and silver mines carried less chlorine than those of copper mines, the average of 19 being 23.8. Exclusive of four samples showing traces, the average is 30.2. The chlorine content of waters of well-drained areas like those of Ducktown, Tenn., and Creede, Colo., is conspicuously low. The amount of chlorine in deposits in or near arid regions or near the sea is greater. Two samples from Butte, Mont., show a large content of chlorine. In general the chlorine content in the samples analyzed is much lower than in samples of water obtained by Don² from a large number of Australasian mines and considerably lower than a former estimate (873 parts per million) given by me in a previous paper³ on the concentration of gold by cold solutions.

Carbonates.—Since sulphuric acid tends to drive carbon dioxide out of solution, it would not be supposed that highly carbonated waters would be common in mines where the ore carried much pyrite. That small amounts of acid sulphate and carbonates may exist in the same solution is shown, however, by several analyses. In the acid waters under consideration the carbonates of the bases would necessarily be present as bicarbonates, although this fact is not indicated in all the analyses.

Carbonates were determined in only one sample of water from copper mines but are probably present in others. Carbonates are shown in 13 waters from gold and silver mines, the average of the 13 samples being 224.6 parts per million. The average of the 19 samples from precious-metal mines is 153.7 parts. Two waters from the Geyser mine, Custer County, Colo., and two from Creede, Colo., contain, in addition to the carbonate radicle (CO_3), considerable excess carbonate calculated as carbon dioxide (CO_2), but this is not included in the average. Several analyses of waters from mines of Butte, Mont., show insufficient carbon dioxide in the bicarbonate

¹ Penrose, R. A. F., jr., The superficial alteration of ore deposits: Jour. Geology, vol. 2, 1894, pp. 314-316

² Den, J. R., The genesis of certain auriferous lodes: Trans. Am. Inst. Min. Eng., vol. 27, 1898, p. 654.

³ Emmons, W. H., The agency of manganese in the superficial alteration and secondary enrichment of gold deposits in the United States: Bull. Am. Inst. Min. Eng., 1910, p. 774; Jour. Geology, vol. 19, 1911, p. 20. To obtain this estimate many partial analyses were included. These are not given in the table on pages 62-63.

state to satisfy the bases, hence both normal and bicarbonates were assumed as present and the summation was raised to correspond.¹

Silica.—The analyses show that appreciable silica is dissolved even in strongly acid mine waters. Very little is known concerning the conditions that favor the solution of silica in such waters. Solutions that contain much alkali and carbonate generally carry larger quantities of silica, although the one that carries the most silica is a concentrated sulphate solution from the Comstock lode. The average silica content of 18 waters from copper mines is 44.7; that of waters from 19 precious-metal mines is 69.4.

Arsenic and antimony.—Arsenic and antimony compounds are dissolved in some mine waters, for there is evidence that minerals containing these metals are deposited from cold solutions. Only traces of arsenic and antimony are reported in the analyses, but Dr. Hillebrand notes that considerable arsenic was present in a precipitate from a filtered sample of water collected by Waldemar Lindgren at Grass Valley, Cal., where the gold ores carry arsenical minerals. Traces of arsenic are reported in three waters from Butte, Mont.

Nitrates.—Nitrates are not abundant in mine waters. In only one analysis (20) is nitrate (NO_3) reported (1.60 parts per million), and this in a water that was questionably representative, for it appears to have been imperfectly filtered.²

Phosphates.—Traces of phosphate are reported in eight mine waters. One sample contained 1.5 parts per million; others contained none, if determinations for phosphate were made.

Potassium.—Potassium has been found in all the samples of waters from copper mines where it was looked for. The average of 13 samples is 10.7. In the samples from gold and silver mines it varied from 1 part to 254 parts per million, the average of 14 samples being 53.9. If it is assumed to have been absent in the five samples in which it is not reported, the average content of 19 samples is 39.7.

Sodium.—Owing to its greater solubility in sulphate solutions, sodium is generally more abundant than potash in these mine waters. The 18 samples of waters from copper mines contained an average of at least 24.8 parts per million, and 13 samples in which potash was determined averaged 34.4. The average sodium content of 14 samples of water from precious-metal mines is 131.6 parts per million.

Calcium.—The average calcium content of 18 samples of waters from copper mines is 209.3 parts per million. The average of 19

¹ Hillebrand, W. F., Composition of mine waters, in Weed, W. H., Geology and ore deposits of the Butte district, Montana: Prof. Paper U. S. Geol. Survey No. 74, 1912, p. 101.

² Emmons, S. F., The mines of Custer County, Colo.: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 462; analysis of water from Geyser mine, Silver Cliff, Colo. See also statement of W. F. Hillebrand, analyst, on page 460 of same report.

samples of waters from precious-metal mines is 144.2 parts. Calcium was determined in every sample.

Magnesium.—In 18 samples of waters from copper mines magnesium averages 47.4 parts per million. In 19 samples of waters from precious-metal mines it averages 390 parts. In three samples of such waters it is not reported. In 16 waters of precious-metal mines it averages 445.2 parts per million. The remarkable concentration of magnesium in sample 23 (an exceptional water) brings the average far above that of calcium, but notwithstanding the greater solubility of its sulphate, magnesium exceeds calcium in only three of the samples.

Aluminum.—Like the alkalis and alkaline earths, aluminum is readily dissolved from the silicates of the ore or from the wall rock. In general it is more abundant in sulphate waters than in those that carry considerable carbonate.

The average aluminum in 12 samples from copper mines is 81.5 parts per million. Singularly enough it is absent in five waters from mines at Butte, Mont., which are in "granite." It is reported from only eight samples of water from precious-metal mines, the average being 1,209.9. If analysis 23, which shows exceptionally high alumina, is excluded, the average of the 18 other samples is only 1.3 parts per million.

Manganese.—In 16 samples of water from copper mines the average content of manganese is 40.8 parts per million. In one analysis it is not reported; in another a trace is shown. It is especially abundant in the waters from Cananea, Sonora, Mexico.

The average of 13 samples from precious-metal mines is 81.5 parts per million. It is not reported in six. The variation in manganese content is exceedingly great. Only two waters, one from the Comstock lode and another from the Stanley mine, Georgetown, Colo., contain more than a few parts per million.

Iron.—All the 18 samples of water of copper mines contain iron. In two of them it is stated as total iron; in 14 samples ferrous iron is present, the average of these being 303.9 parts per million; ferric iron is present in 7 samples. Ferrous iron was probably determined in 15 samples, the average of the 15 being 23.3 parts per million indicating that in such waters, even in the zone where air is admitted, ferrous iron predominates in many mines. None of the analyses of samples taken underground at Cananea (Nos. 14–18) show ferric iron, yet the sample taken from the concentrates, where it circulates over the tables in contact with ore and air, contains appreciable ferric iron.

In two samples of water from precious-metal mines iron is stated as total iron. Ferrous iron is reported from 5 of the 17 samples remaining, the average being 34.8 parts per million; or if it was determined in all 17 samples, the average is 10.3 parts per million.

It is highest in the water from the Stanley mine. Appreciable ferric iron is reported in six samples, its average being 841 parts per million. Excluding sample 23. from the Comstock lode, the average of the other five samples is only about 5 parts per million. This is lower than the ferric iron in waters from copper mines and very much lower than the ferric iron determined by Don in many waters from Australasian mines.

Copper.—Copper, dissolved as sulphate, is abundant in many mine waters. In some mines at Butte, Mont., Ducktown, Tenn., Jerome, Ariz., and Rio Tinto, Spain, and in the Ballygahan mine, Wicklow, Ireland, the waters during certain periods of development have been sufficiently cupriferous to yield marketable quantities of copper. The average of 13 samples from copper mines is 3,690 parts per million. In five samples it is absent or is not reported. The water from the Mountain View mine at Butte, Mont., is by far the most highly cupriferous. Exclusive of this the average of 12 samples is only 195.5 parts per million. Copper is reported also in a concentrated water from the Comstock lode (No. 23) and in water from the Stanley mine at Georgetown, Colo. (No. 35), and traces are present in waters from other precious-metal mines (19 and 20).

Zinc.—The zinc content of the waters of 15 copper mines averages 140.3 parts per million. The average of 19 samples of precious-metal mines is 6.7 parts per million. In the seven of these from which it is reported the average is 18.3 parts per million. Some waters from mineral deposits of the Mississippi Valley contain abundant zinc.

Gold and silver.—Small amounts of gold and silver have been detected in waters from the Comstock lode,¹ and gold has been determined in a water from the Homestake mine, in South Dakota.² Traces of both gold and silver are present in waters from the Granite vein Montana.

CHANGES IN COMPOSITION DEPENDING ON DEPTH.

Waters descending from the surface through sulphide ore deposits pass through a changing chemical environment and are continually changing in chemical composition. In the oxidized zone, as already stated, they are oxidized waters and acid waters; when they pass below the region where oxygen is in excess their acidity and their state of oxidation change. Their reaction on some sulphides produces hydrogen sulphide, and their reaction on silicates and carbonates decreases acidity. Iron is generally abundant in waters of pyritic ore bodies, and the degree of the oxidation of the iron is important as an index to the state of oxidation of the water. Mineral waters

¹ Reid, J. A., The structure and genesis of the Comstock lode: Bull. Dept. Geology Univ. California, vol. 4, 1906, pp. 189, 192.

² Sharwood, W. J., Analyses of some rocks and minerals from the Homestake mine, Lead, S. Dak.: Econ. Geology, vol. 6, 1911, p. 742.

may thus be divided into several groups, depending on the degree of their oxidation and their acidity. Nos. 9, 10, and 11, from Ducktown, Tenn., are samples of waters containing acid and ferric sulphate. Samples of acid and ferrous sulphate water are represented by No. 7, from the Ruth mine, Ely, Nev.; Nos. 8, 12, and 13, from Ducktown, Tenn.; No. 35, from the Stanley mine, Georgetown, Colo.; and No. 32, from the Rothschönberger Stolln, Freiberg, Germany.

Of the 37 samples of water analyzed 13 or more carry no free acid, and 9 of these are alkaline. The alkaline waters include two (33, 34) from the deep levels of mines at Creede, Colo., where they descended to depths of 1,300 feet or more before they issued at the drain level. As would be supposed, ferric iron is not present in any of the nine analyses of alkaline waters.

Samples 27 and 28 are waters collected by Waldemar Lindgren from the 400-foot levels in the Federal Loan and Black Prince mines at Nevada City, Cal. As the temperature of these waters when collected was the same as that of the surrounding rock, they come, presumably, from the meteoric circulation. Both are alkaline and both form yellow-brown deposits consisting principally of hydrated iron oxide, alumina, and silica. These waters were clear when bottled, but when opened after several months both contained dark-colored deposits of silica, hydroxides, and sulphides. Dr. W. F. Hillebrand, who made the analyses, detected no hydrogen sulphide in either water, although both appeared to contain a little thiosulphate. Sample 27 contained metallic sulphides in solution, and an odor of hydrogen sulphide was noticeable near the place where it was obtained. Sample 28 contained no metallic sulphides and emitted no noticeable odor of hydrogen sulphide. At least eight additional samples (8, 9, 10, 11, 12, 13, 33, and 34) have been tested for hydrogen sulphide, with negative results. Sample 2 deposited sulphur and ferrous sulphides.

Although hydrogen sulphide is rare in mine waters, it forms when certain sulphides are in contact with acid. When exposed to the air it oxidizes rapidly. It is not supposed that it would accumulate, at least not in the zone where air has free access to the deposits, where most samples of mine waters are taken. On descending to greater depths it would be used up according to the reaction—



or it might be used up also in the precipitation of metallic sulphides from sulphates. Whether it would be used first to form ferrous sulphate and afterward to precipitate metallic sulphides can not be shown, but this order of action occurs at least under some conditions. Samples 8 and 9, from Ducktown, Tenn., are especially instructive in this connection, for No. 8 contains much ferrous iron and no ferric iron, whereas No. 9 contains much ferric iron and only 1.3 parts of

ferrous iron. The ore through which sample 8 passed before issuing where it was taken is more than 90 per cent pyrrhotite, which generates hydrogen sulphide rapidly. The ore through which sample 9 passed contains chiefly chalcopyrite and lime silicates, with but little pyrrhotite. This water contains considerable iron, almost all in the ferric state. Since No. 8 contains even more copper than No. 9, it would be supposed that the ferric sulphate is reduced to ferrous sulphate (FeSO_4) before copper sulphide is precipitated, as in this water the iron is entirely reduced to the ferrous state while there is still a considerable amount of copper in solution. It is noteworthy that the alkaline waters (samples 27, 28, 33, 34) contain appreciable quantities of carbonates, with lime, potash, and soda. They carry also a certain concentration of sulphates. Two of the four alkaline waters from Nevada City, Cal., and two from Creede, Colo., have descended through considerable unoxidized material. Alkaline waters have not received sufficient attention in studies of sulphide enrichment.

Samples 14, 15, 16, and 17 are from the Capote mine, at Cananea, Mexico. The deposit is in an area of quartzite and other rocks intruded by diorite porphyry. The ore is in part of the disseminated type and carries pyrite, chalcopyrite, and zinc blende, with secondary chalcocite. I can not state the vertical range of chalcocite in this deposit, but it is not so abundant at the 900-foot level, where sample 16 was obtained, as it is at the 300-foot level, where sample 14 was obtained. Sample 14 contains 970 parts of free acid per million, whereas the samples taken at greater depths contain no free acid.

The two pairs of samples Nos. 10 and 11 and Nos. 12 and 13 are from unused shafts at Ducktown, Tenn. As stated above, the samples were taken by lowering bottles equipped with asbestos filters to the desired depth, then removing the covers from the filters and allowing the bottles to fill. The waters from the open shafts are diluted by a large proportion of surface water, so they are less concentrated than mine waters that have traveled considerable distances through the rocks. In taking samples 10 and 11 the water was disturbed, so that the analyses of these samples are of less value; samples 12 and 13 were taken with special precautions to prevent agitation and show very well the difference in the mineral content of the waters at different depths. The water from the surface (No. 12) contains more than twice as much free acid as the deeper water. No. 13, taken below water level, is more concentrated with respect to silica, calcium, magnesium, aluminum, zinc, and iron, but the concentrations of potassium, sodium, and manganese are closely similar. The amount of copper is greatly decreased. This suggests that at a depth of 37 feet other metals are being taken into solution but the greater part of the copper has already been deposited. Although the deeper water contains more ferrous iron and more ferric iron than that at the water level, the proportion

of ferric to ferrous iron has increased with increase of depth, showing just the reverse of the conditions expected. It is thought that the increase in the proportion of iron in the solution with increase of depth has been brought about by reaction of acid on pyrrhotite and also that ferric iron has decreased near the surface by hydrolyzation. The filter paper was colored red by a dustlike iron precipitate, probably basic ferric sulphate, formed presumably near the surface and held in suspension in the water. The formation of this precipitate probably accounts for the very small concentration of ferric iron at the surface of the standing water and possibly also for the somewhat smaller amount of total sulphate held in solution near the surface. This precipitate would probably not form so extensively under conditions affording free circulation.

The four waters from Freiberg, Germany (samples 29, 30, 31, 32), agree in containing considerable zinc and manganese. One of them on standing forms a deposit consisting chiefly of manganese oxide and some zinc oxide.

Sample 20 is from the 2,000-foot level of the Geyser mine at Silver Cliff, Colo. This water contained some nitrate, which is uncommon in analyses of mine waters.

Several of these waters do not contain a sufficient amount of the acid ions to hold in solution the metallic portion. If carbon dioxide was determined in such waters, a part of the metals must be dissolved as silicates or possibly even as hydroxides.

PRECIPITATES FROM MINE WATERS UNDER SUPERFICIAL CONDITIONS.

Many waters, after issuing from mineralized areas, deposit copious precipitates. In some mining districts the streams which carry away the underground drainage from the adits have stained their beds for great distances from the points of issue. In certain of these areas, as at Cananea, Mexico, and Bingham, Utah, the gravels above the present streams are cemented by iron oxides, showing that the processes of precipitation at the surface were operative before the mines were opened. These deposits, formed under atmospheric pressure and in the presence of oxygen, are very different from the deposits of secondary ore that are formed at depths where sulphide enrichment is assumed to take place. Few if any of them are workable for the more valuable metals. Nearly all of them consist largely of the colloidal compounds, such as the hydrous iron oxides, hydrous aluminum compounds, and hydrous silica.

Many samples of waters quickly become cloudy after they have been filtered, either because of their filtration in air or because of slight changes in their temperature; or, if they have been taken from low depths, because of decrease in pressure precipitation takes place. Two samples of water taken from adits at Creede, Colo., and filtered in the presence of air deposited light-gray precipitates, presumably compounds of aluminum and silica. Of six samples

collected at Ducktown, Tenn., all were likewise clouded. Two of these samples, one taken 37 feet and the other 55 feet below the water level, were filtered under water, and although the air spaces left in the necks of the bottles were exceedingly small the samples clouded in a few hours. Several samples from Butte, Mont., deposited solids before analyses were made.

The results of analyses of four samples of material precipitated from mine waters are stated in the table below. Sample 1 is from a water in the Stanley mine, near Georgetown, Colo. (No. 35 in table above). Sample 2 is from a mine in Freiberg, Saxony. The sample was taken from workings that had been flooded 135 years. It contained much manganese and considerable zinc. Sample 3 is a slime collected in the Federal Loan mine,¹ near Nevada City, Cal., where the water represented by sample 23 of the table on page 62 issued from the wall rock. Of this analysis Dr. Hillebrand makes the following remarks:²

The bottle was filled with a black slimy matter emitting a disgusting odor of organic decomposition. The cork was forced out with ease by imprisoned gas, chiefly consisting of CO₂ and CH₄. The slime was said to have been white when collected; the subsequently developed black color is due to iron sulphide. Aside from organic matter and water, the deposit is essentially ferric oxide with a little arseniate, calcium carbonate with a little magnesium carbonate, and manganese as MnO₂, besides gelatinous silica and fragments of minerals.

A deposit collected by Lindgren in the drain tunnel of the Providence mine, near Nevada City, Cal., when dried, formed dirty white masses and coarse green lumps. An analysis of some of the green pieces is given in column 4 of the following table:

Analyses of muds precipitated from mine waters.

	1	2	3	4
SiO ₂	10.85	^a 3.55	18.4	8.31
Al ₂ O ₃	2.87	.....	.....	37.57
Fe ₂ O ₃	53.57	7.78	23.3	.44
FeO.....	.....	.....	.....	.....
MnO ₂.....	.....	^b 53.21	.6	.....
CaO.....	.....	.....	10.8	.12
MgO.....	.....	.....	.....	Trace.
Pb.....	.....	.....	Trace.	.....
CuO.....	.....	3.20	.....	.57
ZnO.....	.....	6.08	.....	.....
Mo.....	.....	.....	.....	Trace.
As.....	.....	.....	1.3	.....
Na ₂ O.....	.....	.....	.....	.17
SO ₃	11.46	.67	.5	9.51
H ₂ O.....	21.14	19.99	34.9	42.98
	99.89	99.48	99.8	99.67

^a Insoluble residue. ^b Some MnO present. The analysis as stated gives O, 8.43, and MnO, 44.78.

1. Precipitate filtered from water of Stanley mine. Jones, L. J. W., Ferric sulphate in mine waters and its action on metals: Proc. Colorado Sci. Soc., vol. 6, 1900, p. 48.

2. Deposit from a mine at Freiberg, Saxony, taken from workings that had been flooded 135 years. Contains cobalt oxide, 1.36; cadmium oxide, 0.19; lead oxide, 3.45. Beck, Richard, Lehre von den Erzlagerstätten, 1901, p. 402.

3. A deposit from water from Federal Loan mine, near Nevada City, Cal. CaO equals CaCO₃ and MgCO₃; organic material calculated with water. Insoluble material included with SiO₂. Lindgren, Waldemar, The gold-quartz veins of Nevada City and Grass Valley districts, California: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 122.

4. Part of deposit in drain tunnel of Providence mine, near Nevada City, Cal. Idem, p. 123.

¹ Lindgren, Waldemar, The gold-quartz veins of Nevada City and Grass Valley districts, California: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 121.

² Idem, pp. 122-123.

OXIDATION AND SOLUTION OF CERTAIN METALLIC SULPHIDES.

FACTORS CONCERNED.

In the presence of air the oxidation and the solution of the metallic sulphides take place simultaneously and it is difficult if not impossible to consider the two processes separately. The rate of solution depends on many factors, among them (1) the solubility of the material in water, (2) the molecular and physical structure of the material, (3) the solubility of the salts formed by oxidation, hydration, and related processes, (4) the composition, concentration, temperature, and pressure of the solutions, (5) the mineral and chemical environment, (6) the rapidity of circulation, and (7) the potential or electromotive force of the mineral compared with the electromotive force of the mineral or minerals with which it is in contact.

It is noteworthy that the natural conditions are not those which commonly exist in the laboratory, for in nature the solvent is in motion and is therefore bringing new and generally unsaturated solutions into contact with bodies that are dissolving. Thus, if sufficient time is afforded even minerals that in the laboratory are most nearly insoluble may by natural processes be completely dissolved. Even salts so insoluble as cerargyrite and anglesite may be entirely removed from the outcrops of ores.

The solubilities of the sulphates that are formed by these reactions are nevertheless important, for, other conditions being similar, it would be supposed that the metals that have the most soluble sulphates would be most readily dissolved. As shown by the table of solubilities, iron, zinc, and copper have highly soluble sulphates, whereas the solubilities of the sulphates of lead and silver are low. Although galena (p. 59) is readily attacked by cold dilute sulphate solutions it is nevertheless slow to dissolve in metalliferous deposits. This fact may indicate why lead lags behind iron, copper, and many other metals in its migration downward in ore deposits.

Pyrite and marcasite, which have the same formula, oxidize and dissolve at different rates, owing, probably, to a difference in their molecular structure. Cellular pyrite will oxidize more rapidly than dense pyrite.

The importance of an oxidizing environment as a condition for the solution of some metals should be emphasized.

All the experimental evidence shows that the oxidation and solution of the sulphides in pure water is slow. Under natural conditions it may be accelerated somewhat by carbon dioxide, which is generally dissolved in rain water and forms a weak acid that may start solution. Sulphuric acid, a more powerful solvent, is released in the presence of iron sulphides.

The recent work of Gottschalk and Buehler¹ shows that several sulphides in contact in water form weak batteries. The current flows from the mineral having the higher potential to the one having the lower potential, which is dissolved, the one with higher potential being to some extent protected from solution. These experiments should probably be interpreted as indicating particularly the relations that exist at the beginning of solution, for the electromotive force varies with variations in the solutions, which, as already stated, are continually changing. The relations considered are those which exist in the presence of free air. Under natural conditions all portions of oxidizing deposits are not equally accessible to atmospheric oxygen. Some sulphides that are readily dissolved in dilute acid sulphate in the presence of air are practically insoluble in its absence. Chalcocite, for example, is highly stable in portions of deposits where air is excluded, but in the presence of air and acid it dissolves very readily. The solution and oxidation of the sulphides depend on so many factors that general statements can not be applied to all conditions or combinations, each mineral association presenting, in a sense, a problem in itself.

RELATIVE RATE OF SOLUTION OF SEVERAL SULPHIDES IN AN OXIDIZING ENVIRONMENT.

The following table shows the order of oxidation of some of the sulphides, according to the views of several investigators. The sulphides that are most readily attacked are placed highest in each series. The differences that appear between certain of the series might be interpreted as indicating differences which should be expected under natural conditions, the order of oxidation depending on the environment.

Order of oxidation of sulphides, according to several authorities.

1	2	3	4	5	6	7
Iron. Copper.	Arsenopyrite. Pyrite. Chalcopyrite.					Pyrrhotite. Sphalerite.
Zinc. Lead. Silver.	Sphalerite. Galena. Chalcocite.	Chalcocite.	Chalcocite. Pyrrhotite.	Chalcocite. Bornite. Pyrrhotite. Chalcopyrite.	Sphalerite. Chalcocite. Galena. Pyrite. Chalcopyrite.	Galena. {Chalcopyrite and pyrite.
		Pyrite.	Pyrite.	Pyrite.	Argentite.	

1. Van Hise, C. R., Some principles controlling the deposition of ores: Trans. Am. Inst. Min. Eng., vol. 30, 1901, p. 101.

2. Weed, W. H., The enrichment of gold and silver veins: Trans. Am. Inst. Min. Eng., vol. 30, 1901, p. 429.

3. Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 180. At some places in Clifton district.

4. Emmons, W. H., and Laney, F. B., Preliminary report on the mineral deposits of Ducktown, Tenn.: Bull. U. S. Geol. Survey No. 470, 1911, pp. 151-172. Above the water level.

5. Vogt, J. H. L., Problems in the geology of ore deposits, in Pošepný, Franz, The genesis of ore deposits, 1902, pp. 676-677. Order of attack of sulphides by ferric chloride.

6. Gottschalk, V. H., and Buehler, op. cit., p. 31. Table showing relative potential of several sulphides.

7. Wells, R. C. Table showing rate of attack of 0.057 normal solution H_2SO_4 on several sulphides. (See p. 59.)

¹ Gottschalk, V. H., and Buehler, H. A., Oxidation of sulphides: Econ. Geology, vol. 7, 1912, p. 16.

As already stated, the relative rate of solution of the sulphides probably can not be expressed in a hard and fast series, yet certain relations hold under many, probably under most conditions. Sphalerite is so readily dissolved by acid in the absence of air that at many places it is removed even from primary ores that are in a reducing environment. Consequently in many deposits the order of the rate of solution of sphalerite, chalcocite, and pyrrhotite in acid where oxygen is in great excess can not be stated. Possibly sphalerite should be placed at the head of the series shown in the table; possibly it should be placed between pyrrhotite and chalcopyrite.

The relative rate at which chalcocite and pyrite are removed where oxygen is in excess is shown by the relations of these minerals in several deposits. Lindgren¹ notes that in the Morenci district chalcocite is often oxidized, while much pyrite remains. At Ducktown, Tenn., the "black copper" ores, composed of pyrrhotite, pyrite, and chalcocite, which have replaced the iron sulphides near the water level, quickly lose their copper content when the ores are exposed to highly oxygenated waters by the artificial depression of the level of the ground water. Solution is so rapid there that it is difficult to obtain rich chalcocite ores in mines that have been opened below the water level for a few years. At Ducktown, as at Morenci, chalcocite, where oxygen is present, is dissolved more rapidly than pyrite.

The pyrite in some of the leached chalcocite ore of Ducktown remains almost unaffected by the leaching, its bright crystals being distributed through a dark mass of sooty black pyrrhotite, which has been partly altered and from which practically all copper has been removed. The order of solution indicated appears to be chalcocite, pyrrhotite, pyrite.

As shown by Gottschalk and Buehler, galena oxidizes more readily than pyrite. The oxidation product, lead sulphate, is so insoluble, however, that it remains to cover the crystals of galena and serves to delay further action. Galena remains in the outcrops of many sulphide ore bodies after iron and zinc compounds have been completely altered. It is said that some ore deposits in the Wisconsin zinc district were discovered by farmers who plowed up crystals of galena.

Enargite also is an exceedingly persistent mineral in outcrops. According to Reno Sales² it is commonly found in or near oxidized ores of the Butte copper mines, and it is said that at Tintic enargite remains in the oxidized ores even after galena has been dissolved. Series 5 (table on p. 76), based on experiments of Vogt, shows the rate of attack by strong solutions of ferric chloride, an oxidizing agent, on several sulphides. Chalcocite was dissolved quickly, as it is

¹ Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 180.

² Sales, R. H., Discussion of paper by F. L. Ransome, on "Criteria of downward sulphide enrichment": Econ. Geology, vol. 5, 1910, p. 681.

in secondary sulphide zones, where it is exposed to solution in the presence of air. Bornite also was attacked at a relatively rapid rate. Stokes¹ showed that dilute ferric sulphate attacks chalcopyrite more readily than pyrite. All these experiments and observations seem to indicate that in the zone of oxidation in many deposits the sulphides are dissolved in the following order: Sphalerite(?), chalcocite, pyrrhotite, chalcopyrite, pyrite, galena, enargite. This series does not correspond exactly with the series of Wells (column 7 of table), which was obtained from experiments with sulphuric acid alone.

NET RESULTS OF CHEMICAL CHANGES DURING OXIDATION OF CERTAIN ORES.

The results of the chemical changes that take place during the oxidation of sulphide deposits depend largely on the minerals that form the deposits. Some gangue minerals disappear completely, others are partly dissolved, and some elements of still other minerals remain in the mass in new combinations. Not many sets of analyses of sulphide ore and of corresponding oxidized ore from the same deposit are available. The data for the deposits of Ducktown, Tenn., are fairly satisfactory. The gossans of the copper deposits have been smelted for iron, and average analyses of thousands of tons are available from furnace records, through the courtesy of Mr. R. H. Lee and Mr. John B. Newton. Yearly averages from the smelters of sulphide ore from the same deposits are available through the courtesy of the officers of the Tennessee Copper Co. and the Ducktown Copper Sulphur & Iron Co. On the assumption that the average of several specific-gravity determinations of the gossan (2.2) applies to the entire mass and that the average specific gravity of the sulphide ore is 4.05, the following table has been prepared to indicate the nature of the change by which primary ore becomes gossan. Column 1a shows the percentage weight of the constituents of the primary sulphide ore of the Mary mine (average of all ore smelted in 1906). Column 1b shows its percentage weight times its specific gravity (4.05) and may be regarded as expressing the number of grams in 100 cubic centimeters of the primary ore. Column 2a shows the chemical composition of the gossan (average of two large shipments). Column 2b gives its percentage weight times its specific gravity (2.2, corresponding to 39 per cent porosity). Column 3 shows the gain and the loss of several constituents. Losses are shown for sulphur, silica, alumina, lime, iron, zinc, copper; gains for oxygen and water. Carbon dioxide and magnesia were not determined in the analyses of gossan but were probably almost entirely carried away.

¹ Stokes, H. N., On pyrite and marcasite: Bull. U. S. Geol. Survey No. 186, 1910, p. 33.

Chemical changes by oxidation processes at Ducktown, Tenn.

	1a	1b	2a	2b	3
SiO ₂	22.44	90.88	9.95	21.80	— 69
Al ₂ O ₃	2.93	11.87	1.57	3.45	— 8.4
Fe.....	33.43	135.39	49.9	109.78	— 25.6
MgO.....	3.15	12.76	(?)	(?)	— 12.7
CaO.....	8.28	33.534	.35	.77	— 32.7
CO ₂	2.85	11.54	.....	.....	— 11.5
S.....	21.23	85.98	.65	1.43	— 84.5
MnO.....	.44	1.78	.....	.....	.....
Cu.....	2.45	9.92	.86	1.89	— 8
Zn.....	2.79	11.30	.....	.....	— 11.3
H ₂ O.....	.....	.....	* 15.40	22.88	+ 33.88
O.....	.....	.....	* 21.38	47.04	+ 47.04
	99.99	404.954	100.06	220.13	— 182.8

* H₂O and O are estimated, on the assumption that the Fe is in limonite.

Mineralogically the primary ore consists of pyrrhotite, pyrite, chalcopyrite, sphalerite, actinolite, calcite, tremolite, quartz, pyroxene, garnet, zoisite, chlorite, and micas. Small quantities of bornite, specularite, and magnetite are present and at some places graphite, titanite, and feldspars. The following is a close approximation to the mineral composition of the unoxidized ore:

Composition of primary ore at Ducktown, Tenn.

Pyrrhotite.....	38.5
Pyrite.....	5.1
Chalcopyrite.....	7.1
Sphalerite.....	4.2
Quartz.....	10.3
Calcite.....	6.0
Garnet.....	3.0
Amphiboles, pyroxene, zoisite, etc.....	25.8
	<hr/> 100.0

Oxidation has changed this ore into a gossan consisting essentially of limonite with a little silica and kaolin, carrying a fraction of 1 per cent of copper and sulphur.

The table on page 80 shows the results of an analysis of rich concentrates of sulphide ore from the Montana Tonopah mine, Tonopah, Nev., and an analysis of rich oxidized ore from the Valley View vein of the same district. The principal primary minerals in this district, according to Spurr,¹ are quartz, carbonates, adularia, some sericite, and sulphides of silver, antimony, copper, iron, lead, and zinc. Limonite, wad, and horn silver are deposited in the oxidized zone, with some silver bromide, silver iodide, and free gold.

¹ Spurr, J. E., *Geology of the Tonopah mining district, Nevada*: Prof. Paper U. S. Geol. Survey No. 42, 1905, p. 80.

Analyses of ores from Tonopah, Nev.

	1	2
Siliceous matter.....	15.18	16.53
Gold.....	.82	.62
Silver.....	25.92	62.54
Lead.....	6.21	.33
Copper.....	1.32	.09
Iron.....	9.87	1.39
Manganese.....	1.36	.07
Zinc.....	5.84	.10
Selenium.....	2.56	.38
Tellurium.....	None.	None.
Arsenic.....	.19	.08
Antimony.....	.92	.15
Magnesia.....	1.49	.....
Lime.....	3.70	.....
Carbon dioxide.....	6.34	.....
Sulphur.....	Not det.	.....
	81.72	82.22

- 1. Concentrates of primary sulphide ore from Montana Tonopah mine.
- 2. Oxidized ore from Valley View vein.

Discussing the composition of the primary and secondary ores shown by the analyses, Spurr ¹ says:

Aside from the complex carbonate of lime, manganese, magnesia, and iron, the analysis of the primary sulphide ore indicates the presence of a large amount of silver sulphide—argentite. Antimonial sulphides of silver, polybasite, very likely stephanite, and smaller amounts of galena, blende, pyrite, and chalcopyrite are also indicated. Of very great interest is the presence of a considerable amount of selenium, which occurs, in part at least, as a silver selenide, and the absence of its usually closely associated element tellurium. The chemical form of the gold is yet uncertain.

It is fair to assume that the oxidized ore in its primary sulphide state may have had a composition somewhere relatively near that of the primary sulphide analyzed. The two analyses may then be compared with the object of perceiving the changes effected by oxidation. There is no element which can be considered as having remained quantitatively unaffected during oxidation, so that merely the large relations can be glanced at. All the metals except silver and perhaps gold are present in the oxidized ore in much diminished proportions. The lead, copper, and zinc are present in small quantities. The manganese is now in the form of oxide, but very little remains; the iron is in the form of oxide, with some residual or secondary pyrite. There is much less gold in proportion to silver in the oxidized ore than in the sulphide ore; but this may be fortuitous and depend on the specimen selected. More than half the silver is in the form of sulphide, and from the very small quantity of arsenic and antimony present this portion must be nearly all in the form of argentite. The antimonial silver sulphide is very probably pyrargyrite (ruby silver), judging from microscopic observations. It is noteworthy that antimony and arsenic are present in the same proportions to one another in both analyses. There is less than a third as much selenium in the oxidized ore as in the sulphide ore, but the discrepancy is not so great as in the case of lead, copper, manganese, zinc, arsenic, and antimony; and this selenium seems to be still in the form of a silver selenide.

Therefore it is probable that during the process of oxidation the primary carbonates were attacked by surface waters and the lime and magnesia, together with most of the iron and manganese, removed in solution. Some of the iron and manganese remain as oxides. No important change in the amount of gold and silver is proved. The argentite has largely remained unaltered, but the polybasite (and stephanite if

¹ Spurr, J. E., op. cit., pp. 92-93.

present) has probably been attacked, and much of the silver selenide. Part of this silver has been reprecipitated with little change of position as secondary argentite, not distinguishable from the primary argentite, while a large portion has been altered to chloride by the action of chlorine contained in the shallow underground waters. Most of the arsenic and antimony in the original polybasite and stephanite has been removed in solution; the rest goes to form the secondary sulphide pyrrargyrite, as indicated by numerous field observations. The pyrite and the chalcopyrite have been attacked. Most of the iron in these sulphides has been removed; a small part remains as oxide, or rarely as residual or secondary pyrite. Nearly all the copper has been removed, a little remaining in the probable form of oxide.

At Cripple Creek, as noted by Lindgren and Ransome,¹ the original vein structure is destroyed by thorough oxidizing decomposition. In some sheeted lodes having many small parallel fissures and joints these openings become closed or effaced and the lode appears as a homogeneous brown, soft mass. In other places a central seam is retained and appears as a streak of soft, more or less impure kaolin; in still other places a central seam is filled with white compact alunite, more rarely by jasperoid or opaline silica. Crusts of comb quartz, if originally present, lie included in the clayey seams, but neither the original fluorite nor the carbonates are ordinarily preserved. Very rich oxidized ore fills the central cavities of some lodes like a thick brown mud and easily flows out when the vein is opened.

These writers say:²

In general oxidation tends to transform sulphides, sulphosalts, and tellurides to oxygen salts and native metals, both of which may, under certain circumstances, be further changed or carried away by surface waters. The silicates in the veins are changed to a few minerals most stable under atmospheric influences—that is, kaolin, quartz, manganese dioxide, and limonite. The carbonates of the earthy metals are carried away in solution, while those of manganese and iron are changed to oxides. As waters of acid reaction, frequently containing free sulphuric acid, prevail during oxidation of vein deposits, original quartz will not be attacked. New silica, generally hydrated, may be deposited by solutions derived from the decomposition of the silicates.

The processes are more difficult to follow and to establish by means of analyses than those due to primary vein formation, for it seems to be a characteristic feature of oxidation to segregate the new minerals in larger masses and thus produce a less homogeneous product; this is no doubt due to the energetic action of oxygen and of the acids set free, as well as to the increasing mobility of substance near the surface. Oxidation tends to thorough change of composition and also to obliteration of structure of the original rock or vein.

Of the metallic minerals the tellurides form the most important division. The bond between the tellurium and the gold is not a strong one, and direct oxidation very easily produces residual pseudomorphs of free gold and tellurium dioxide (the mineral tellurite), which in presence of iron oxides easily changes to various tellurites such as the yellowish-green emmonsite. In the Bonanza King lode of the Midget mine occur veinlets of pyrite with tellurides. Within 30 or 40 feet of the surface

¹ Lindgren, Waldemar, and Ransome, F. L., *Geology and gold deposits of the Cripple Creek district, Colorado*: Prof. Paper U. S. Geol. Survey No. 54, 1906, p. 199.

² *Idem*, pp. 199-200.

oxidation has changed the tellurides to specks of native gold, while pyrite remains practically unaltered. The tellurides in fissures and joints, which form the most common mode of occurrence, will be most easily oxidized, while those occurring as metasomatic products in the rocks are not so readily reached by the surface waters.

Galena and zinc blende change to lead sulphate and zinc silicate, which may remain or even be somewhat concentrated in the altered mass. Molybdenite oxidizes very readily to yellow and blue molybdate and ilsemannite, products that do not seem to be easily carried away. Tetrahedrite yields various forms of oxidized copper compounds which, as usual, show considerable mobility. No oxidized products containing antimony have been recognized. The fluorite on exposure to oxidation loses its deep-purple color and becomes disintegrated. Eventually a part of it is dissolved in surface waters.

The following table shows the results of analyses of unoxidized ore from the Moose mine (column 1) and the oxidized portion of the same specimen (column 2). The specimens were analyzed by F. C. Knight and have been described by Richard Pearce.¹ Column 3 shows an analysis by W. F. Hillebrand of wholly oxidized ore from the 100-foot level of Stratton's Independence mine.

Analyses of fresh and oxidized ores from Cripple Creek, Colo.

	1	2	3
SiO ₂	56.70	50.55	54.45
TiO ₂.....			.80
Al ₂ O ₃	19.35	19.93	14.45
Fe ₂ O ₃	^a 4.20	10.57	^a 9.94
MnO ₂.....		.27	^b 1.71
CaO.....			1.14
MgO.....	.37	.12	.48
K ₂ O.....	} ^c 13.97	} ^c 12.13	{ 9.96
Na ₂ O.....			
ZnO.....			^d .53
CuO.....			.08
PbO.....			.18
Bi ₂ O ₃.....			.0025
MoO ₃.....			.008
TeO ₂.....	.10	(TeO) .79	.19
Au.....	.041	.049	.52
Ag.....	.022	None.	.02
SO ₃		2.55	.10
P ₂ O ₅.....			.50
H ₂ O.....	.50	3.05	Not est.
CO ₂			Trace.
S.....	4.75		
	100	100.00	^c 95.4205

^a Both Fe₂O₃ and FeO present.

^b Both MnO₂ and MnO present.

^c By difference.

^d Possibly high.

^e The difference is largely made up of combined water.

Of these analyses Lindgren and Ransome² say:

From the analyses and from what is known about the normal composition of unoxidized ore the following conclusions may be drawn, although it is of course realized that much more analytical work would be necessary for an exhaustive treatment of this difficult subject.

¹ Pearce, Richard, Further notes on Cripple Creek ores: Proc. Colorado Sci. Soc., vol. 5, 1896, pp. 11-18.

² Lindgren, Waldemar, and Ransome, F. L., Geology and gold deposits of the Cripple Creek district, Colorado: Prof. Paper U. S. Geol. Survey No. 54, 1906, pp. 202-203.

During oxidation the percentage of silica decreases moderately, probably by solution of silica set free during the decomposition of silicates. Alumina remains fairly constant, though it may locally concentrate to pure kaolin. The iron is apt to locally increase by concentration as limonite, though a part will be carried away as sulphate. Small amounts of lime and magnesia are probably leached from the rock, but the quantity is not greatly changed. Manganese is greatly concentrated, locally, on the seams of the rock. As to alkalies, the accumulation of potassium begun during the vein-forming process is continued or at least maintained during oxidation. Pyrite is converted into sulphuric acid and sulphates, and the percentage of sulphur is greatly decreased in the oxidized ore. Part of it remains as sulphate, but as there appears to have been no corresponding decrease of the bases it would seem likely that a considerable part of it was carried away as free acid. Little change is noted in the titanium, while phosphoric acid and zinc appear to have increased. The small quantities of other metals do not seem to differ notably from those observed in fresh vein material. An increase of water to 3 or 5 per cent is a natural consequence of the formation of kaolin and other hydrated salts; locally it may increase up to 14 per cent, which is the amount contained in pure kaolin.

Silver and tellurium are removed by oxidation, but in general gold has remained. It is not easy to demonstrate whether a slight enrichment has taken place or not. Lindgren and Ransome incline to the belief that the oxidized ores as a whole are somewhat richer than the corresponding telluride ore, but this difference may depend on the original unequal distribution of the gold.

RELATIVE RATE OF SOLUTION OF SEVERAL SULPHIDES IN A REDUCING ENVIRONMENT.

When oxygen is present the process of solution is so intimately related to that of oxidation that their results can not be considered separately. The experiments of Wells on the solution of pyrrhotite, sphalerite, galena, chalcopyrite, and pyrite in dilute sulphuric acid were made in stoppered test tubes, and although no special precaution was taken to exclude atmospheric air, yet the excess of hydrogen sulphide generated in at least three of the experiments indicates a reducing environment. The minerals were attacked in the following order, determined by the amount of hydrogen sulphide generated from the three first named: Pyrrhotite, sphalerite, galena, chalcopyrite, and pyrite. This series does not agree closely with any of the others named above. Possibly the electric currents that may be generated when two of the minerals are in contact would modify the rate of solution, but it should not be supposed that the series obtained under reducing conditions in acid would be identical with the series obtained by Gottschalk and Buehler in distilled water with free access of air.

The series obtained from Wells's experiments may not apply everywhere, but geologic evidence indicates that it applies to some deposits. Thus, in the Morenci district, according to Lindgren,¹ the

¹ Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 183.

solutions that deposit chalcocite in the secondary sulphide zone appear not to attack pyrite as long as zinc blende is present. Pyrrhotite also is attacked more readily than pyrite in the chalcocite zone at Ducktown, Tenn. In some ore the pyrrhotite has been reduced to a powdery mass while pyrite remains fresh and untarnished.

METASOMATIC REPLACEMENT OF PRIMARY SULPHIDES BY SECONDARY SULPHIDES AND RELATIONS INDICATED BY SCHUERMAN'S SERIES.

As already stated, the series of Schuermann does not agree exactly with the solubilities of all the sulphides involved; but if comparatively unimportant metals, such as arsenic, antimony, cobalt, and bismuth, are eliminated the series is almost the same as that indicated by the molar solubilities of the sulphides as determined by Weigel. The positions of zinc sulphide and iron sulphide are reversed, but according to Weigel the molar solubilities of these are almost the same. As Schuermann himself observed, the farther apart in the series any two sulphides are the more nearly complete is the replacement.

In the processes of sulphide enrichment the primary sulphides are commonly replaced pseudomorphously by the secondary sulphides. Eliminating the relatively unimportant sulphides, such as those of cadmium and bismuth, and the sulphides of arsenic and antimony, which generally enter into composition with more than one other element to make the more complex secondary minerals, Schuermann's series (and Weigel's series, except zinc sulphide) is as follows: Mercury, silver, copper, lead, zinc, iron. In the table below, for convenience in inspection, the metals are placed in order of increasing solubilities of their sulphides in water, the more soluble sulphides being placed to the right of and below the less soluble ones.

Metasomatic replacement of several sulphides.

[In the order of Schuermann's series.]

Mercury.	Silver.	Copper.	Lead.	Zinc.	Iron.
Mercury.					
Silver.		?	On PbS.	On ZnS.	On FeS ₂ .
Copper.			Metasomatic.	Pseudomorph.	Pseudomorph.
Lead.				On ZnS.	On FeS ₂ .
Zinc.					"Drives out iron."
Iron.					

According to Schuermann's series it might be supposed that mercury sulphide would replace the sulphides of silver, copper, lead, zinc, and iron; that silver sulphide would replace the sulphides of copper, lead, zinc, and iron; that copper sulphide would replace the sulphides of lead, zinc, and iron; and so on.

The search for well-authenticated examples to fill in the several blocks in the table has been only partly successful. It would hardly be supposed that mercury sulphide would replace extensively the more soluble sulphides of other metals, for the solutions that transport the metals are, as already stated, sulphate solutions, and mercury sulphate has exceedingly low solubility. Moreover, mercury is driven out of combination by several metals and tends to form the native metal and the chloride. Secondary cinnabar is not unknown, however, in the oxidized zone. Silver dissolves in dilute sulphuric acid solutions in the presence of ferric sulphate, and at depth its sulphide is precipitated on those of lead, zinc, and iron. Hintze¹ mentions pseudomorphs of argentite after proustite, stephanite, and pyrargyrite, but no examples of pseudomorphs of argentite after sphalerite, galena, or pyrite are available. The occurrences of secondary argentite are generally described as incrustations on the primary sulphides or as veinlets cutting them. Secondary chalcocite frequently contains silver which is disseminated through and doubtless contemporaneous with the copper sulphide, but the nature of the silver mineral is uncertain. The precipitation of silver sulphide at the expense of sphalerite has recently been emphasized by Irving and Bancroft² in their discussion of secondary processes of enrichment of silver ores at Lake City, Colo. In view of the fact that copper sulphide is highly stable in acid solutions in the absence of an oxidizing agent it is not remarkable that the replacement of copper sulphides by silver sulphides is not common in the deeper zones.

Copper is much more abundant in its deposits than silver and the nature of its changes are more easily recognized. Long ago it was pointed out by Genth³ that copper sulphide replaces galena in deposits at Ducktown, Tenn., and B. S. Butler found examples of covellite replacing galena in the San Francisco district, Utah. As stated above, Lindgren has shown that copper sulphide replaces sphalerite at Morenci, and Butler found exceptionally clear examples of the replacement of zinc sulphide by covellite in the San Francisco district. It is said that copper sulphide replaces sphalerite at Butte, Mont., and without much doubt similar replacement is common in many mineral deposits. Examples of the pseudomorphous replacement

¹ Hintze, Carl, *Handbuch der Mineralogie*, vol. 1, p. 442.

² Irving, J. D., and Bancroft, Howland, *Geology and ore deposits near Lake City, Colo.*: Bull. U. S. Geol. Survey No. 478, 1911, pp. 64-65.

³ Genth, F. A., *Contributions to mineralogy*: Am. Jour. Sci., 2d ser., vol. 33, 1862, p. 194.

of pyrite by copper sulphide are well established and numerous, this method being the most common mode of origin of secondary copper sulphide ores. Some examples are enumerated on page 104. Although there are well-authenticated examples of sulphide enrichment of lead deposits, the pseudomorphs of galena after zinc and iron sulphides are not common. Hintze¹ notes one replacement pseudomorphous after sphalerite and one after arsenopyrite. Statements are made that lead has driven iron or zinc out of its sulphide combinations, but lode ores afford surprisingly few examples of pseudomorphous replacements of sphalerite or pyrite. Possibly the strong tendency of galena to assume its own crystal form has obscured its pseudomorphic replacement of other minerals.

It has frequently been stated that zinc sulphide has been precipitated at the expense of iron sulphide and that zinc has driven iron out of its sulphide combination, but no examples of the pseudomorphous replacement of pyrite or marcasite by zinc blende are available. On the other hand Hintze² notes a pseudomorph of marcasite after zinc blende.

It would not be supposed that under the usual conditions of concentration in the secondary sulphide zone a sulphide that appears to the right of the serrate line in the table on page 84 would replace one to the left of it on the same line. Thus the copper sulphides would not be replaced by lead sulphide or zinc sulphide, and so on. Some examples, however, do not agree with the relations indicated in this series,³ for there are pseudomorphs of pyrite after chalcopyrite, arsenopyrite, argentite, stephanite, polybasite, ruby silver, and tetrahedrite, and pseudomorphs of marcasite after pyrrhotite, pyrite, galena, argentite, sternbergite, stephanite, polybasite, miargyrite, bournonite, chalcopyrite, zinc blende, and other minerals.

The conditions that exist where the pseudomorphs are formed at the expense of the less soluble sulphide can not be stated. It would not be supposed that in cold acid solutions, under conditions that prevail in secondary sulphide zones the more soluble sulphides would be fixed at the expense of less soluble sulphides unless the metal entering into the composition of the more soluble sulphide were present in very high concentration. Probably some of the pseudomorphs mentioned above were formed in alkaline solutions or possibly at high temperatures, and the effect of increased temperature on the solubilities of the sulphides is unknown. It should be noted, however, that the secondary replacements that are clearly of great economic significance are such as would be expected from the relations indicated by the Schuermann series.

¹ Hintze, Carl, *Handbuch der Mineralogie*, vol. 1, p. 481.

² *Idem*, p. 820.

³ *Idem*, pp. 722 and 821.

SOURCE OF THE SULPHUR OF SECONDARY SULPHIDES AND GENERATION OF HYDROGEN SULPHIDE.

The acid sulphate solutions that carry the metals downward from the oxidized zone to a reducing environment can not be regarded as an adequate source of sulphur for the secondary sulphides. Sulphides are almost unknown in mine waters, and in the presence of air hydrogen sulphide or any dissolved metallic sulphide would be oxidized to sulphate. In only two of the 37 analyses on pages 60–63 is sulphur reported—about 1 part per million in the alkaline water of the Federal Loan mine, Nevada City, Cal. (No. 27), and in an alkaline water from Butte, Mont. (No. 2). Traces of thiosulphate, probably due to oxidation after bottling, were noted in Nevada City samples (27, 28). Both of these were samples of alkaline solutions obtained from reducing environment.

The sulphate radicle, once formed, is exceedingly stable. It may be broken up by heat, but probably not at temperatures that exist under conditions of superficial alteration. Certain bacteria break up gypsum and other stable sulphates and liberate hydrogen sulphide, but these bacteria can hardly be regarded as an important agency for the generation of hydrogen sulphide, for it is doubtful whether they could survive the presence of copper and other salts, which most of these underground mineral waters carry. It is said that carbon may reduce the sulphate radicle to sulphide, but this statement has not been confirmed experimentally. Organic material, though it has been recognized in some mine waters, is not reported in many of the samples that were taken in glass-stoppered bottles and could have little or no part in the concentration of most lode ores. The only apparent adequate source of the sulphur that combines with the metals to form the secondary sulphides lies in the older sulphides. Where these sulphides are replaced pseudomorphously by secondary sulphides the sulphur has evidently remained in place, and in general the pseudomorphous replacements are attended by loss rather than by gain of sulphur.

As already stated, some of the secondary sulphide ore is found in cracks that cut the older sulphides. In some of these cracks the secondary minerals have replaced an older veinlet of sulphide ore, but in others the ore has clearly been deposited in an open space, which indicates that both the metal and the sulphur that enter into combination to form the secondary sulphide have migrated to the point of deposition. In some districts even secondary chalcocite is known to form veinlets in the older sulphide ore, one of the best examples being afforded by deposits of the Virgilina district, North Carolina, reviewed on page 107. These relations, indicating a transfer of sulphur in some unoxidized form, together with experimental evidence showing that dilute acid in contact with several primary sulphides will generate

hydrogen sulphide, strongly suggest hydrogen sulphide or alkaline sulphides as agents precipitating some secondary sulphides. In view of the fact that sulphur compounds other than sulphates are practically unknown in mine waters, this conclusion might be questioned, but it should be recalled that of the samples available all but two were taken in the presence of air and that these two and many others contain ferric sulphate, which readily decomposes hydrogen sulphide. Hydrogen sulphide is used up in many ways, so it is not surprising that it does not accumulate in the zones of alteration.

PROCESSES OF SULPHIDE ENRICHMENT COMPARED WITH THE PROCESS EMPLOYED FOR SEPARATING THE METALS IN QUALITATIVE CHEMICAL ANALYSIS.

Although it has not been shown that hydrogen sulphide is actually generated by bringing acid sulphate into contact with pyrite or chalcopyrite, or that it is an intermediate product in processes of metasomatic replacement, yet Wells's experiments for producing hydrogen sulphide (p. 59) clearly indicate the power of various sulphides to reduce some solutions or to precipitate sulphides from soluble salts. Without much doubt the same laws of chemical equilibrium apply to both processes, for the mineral that evolves hydrogen sulphide most easily will precipitate a secondary metallic sulphide most readily and will reduce acid solutions of reducible salts most readily.

The method commonly employed in qualitative analysis for separating the metals is as follows: The solution of the metals is made acid with hydrochloric acid, which precipitates silver, lead, and univalent mercury as chlorides. Hydrogen sulphide is passed into the acid solution and precipitates sulphides of lead, bismuth, copper, arsenic, antimony, tin, and bivalent mercury. The filtrate is made alkaline, generally with ammonium hydroxide, and then ammonium sulphide is added, which precipitates the sulphides of iron, manganese, nickel, cobalt, and zinc, also aluminum hydroxide. A review of this procedure may throw light on some of the natural processes of alteration and sulphide enrichment. Mine waters in the oxidized zone—the zone of solution—are acid and generally contain some chlorides. Silver chloride (cerargyrite), mercurous chloride (calomel), or lead chloride or chlorophosphate (pyromorphite) may be fixed in the oxidized zones of deposits carrying the metals indicated, but as chlorides are in general not abundant in mine waters, and as the chlorides named above are themselves somewhat soluble, some of the silver, lead, or mercury may be carried downward by the acid sulphate solutions. Hydrogen sulphide, which, as already stated, is generated by the action of dilute acid sulphate waters on some sulphides, will precipitate from acid solutions arsenic, antimony, tin, bismuth, copper, cadmium, mercury, lead, silver, and gold. These

metals may therefore be precipitated as sulphides before the solution has become less acid. Thus the sulphides of copper, lead, and silver, for example, may be formed at or near the water level, or, in the absence of a water level, in the upper part of the zone of reduction. As the solutions descend they tend to become neutral and ultimately alkaline. When the solutions have lost acidity, sulphides of zinc, iron, and some other metals may be precipitated.

The analogy of the process of separation employed in qualitative analysis is not complete, however, for sulphide enrichment takes place in moving solutions and in solutions probably more dilute; the changes from acid solutions to neutral or alkaline solutions are gradual, especially in deposits not containing minerals that react readily with the solutions, like soluble carbonates and pyrrhotite.

Another relation should be emphasized: Although zinc sulphide is not precipitated by hydrogen sulphide in the moderately acid solution used in the laboratory, it is precipitated in solutions of very feeble acidity. Thus zinc sulphide may be precipitated from a solution of acetic acid. Iron sulphide is less readily precipitated in acid than zinc sulphide. There is not much geologic evidence that either iron or zinc sulphide is precipitated extensively from cold descending acid sulphate solutions which traverse lode ores in igneous or other noncalcareous rocks. In such rocks the descending waters probably remain acid to moderately great depths, for the acid waters do not react on silicates so rapidly as on lime carbonate. These conditions would delay the deposition of secondary iron and zinc sulphides. There is some evidence that secondary chalcopryite, pyrite, and sphalerite are formed in small cracks in the lower parts of some secondary sulphide zones, but they are surely subordinate to secondary copper sulphides in most deposits in noncalcareous rocks. One is warranted in supposing that the precipitation of the iron and zinc sulphides can be brought about only by a nice adjustment of conditions; iron and zinc are not precipitated in solutions that are highly acid, and neutral solutions probably will not vigorously attack the primary sulphides. These relations appear to be in harmony with the geologic observations, which indicate that pyrite and sphalerite are not abundant secondary sulphides in many lode ores. Of the action of alkaline solutions under these conditions not much is known.

DECREASE OF ACIDITY OF DESCENDING SULPHATE WATERS.

In the discussion of the composition of mine waters of sulphide ore deposits it was stated that the waters of the shallow zones are generally acid waters. Moreover, there is considerable evidence that acidity decreases below the water level. Analyses of two samples of water taken from a column of water in the Callaway shaft at Ducktown, Tenn., indicate a decrease in acidity of more than 50

per cent within a vertical distance downward of 37 feet. Some analyses from the Capote mine, of Cananea, Mexico, show also a neutralization of acid at comparatively shallow depths. At least eight other samples, all except one taken at considerable depths, are alkaline. The conclusion is warranted, therefore, that acid solutions descending through sulphide ores decrease in acidity where oxygen is excluded; later they become neutral, and ultimately alkaline. The geologic data are completely in harmony with this conclusion, for there is abundant evidence that descending acid waters attack alkaline or alkaline-earth silicates and alkaline-earth carbonates; acid reacting with feldspars or sericite forms kaolin, and these reactions are attended by the solution of alkalies or alkaline earths as sulphates. Where limestone is attacked decrease in acidity may be attended by precipitation of gypsum.

There are reversals of these processes, it is true, for, according to Stokes, the precipitation of chalcocite is attended by the liberation of sulphuric acid. This acid, however, would soon be neutralized by reactions on silicates and carbonates and could not accumulate permanently. That it is so neutralized is indicated by the common association of secondary copper ore with kaolin or gypsum.

CHANGES IN THE STATE OF OXIDATION OF DESCENDING ACID SULPHATE SOLUTIONS.

The acidity of descending sulphate waters decreases below a certain depth, and because air is excluded the state of oxidation of the solutions likewise decreases. The degree of oxidation of iron, which is generally abundant in mine waters, affords a useful index to the state of oxidation of the solutions. The waters that pass downward from the oxidizing zone carry iron mainly in the ferric state. They may carry also some dissolved oxygen, but not much, for, according to Winkler,¹ at atmospheric pressure and at 16.87° a liter of water can dissolve but 6.84 cubic centimeters of oxygen. Underground waters are, moreover, seldom saturated with oxygen.

Dilute acid sulphate, which reacts on certain sulphides of iron, zinc, and lead, will under some conditions release hydrogen sulphide, which is available (1) for reduction of the oxygen in the water, (2) for reduction of ferric to ferrous sulphate, or (3) for the precipitation of copper or other sulphides which may be held in sulphate solution.

The reduction of the oxygen in the water will probably take place before the copper sulphide is precipitated, since oxygen tends to inhibit the precipitation of copper sulphide. It is probable also that the oxygen of the solution is reduced before ferric sulphate is

¹ Hempel, Walther, *Gasanalytische Methoden*, 1900, pp. 129-130.

attacked, although both reactions may go on together. Assuming the presence of H_2S , we may state the reactions as follows:

- (1) $H_2S + O = H_2O + S.$
- (2) $Fe_2(SO_4)_3 + H_2S = 2FeSO_4 + H_2SO_4 + S.$
- (3)
$$\begin{cases} H_2S + CuSO_4 = CuS + H_2SO_4. \\ CuS + CuSO_4 + H_2S = Cu_2S + H_2SO_4 + S. \end{cases}$$

If oxygen is present the reaction may go on as indicated by (1); if ferric sulphate is present, equation (2) would be possible; with neither oxygen nor ferric sulphate in the solution, equations (3) are possible.

RATE AT WHICH HYDROGEN SULPHIDE IS GENERATED FROM SEVERAL PRIMARY SULPHIDES BY COLD DILUTE ACID SULPHATE WATERS.

As shown by experiments made by R. C. Wells (p. 59), cold dilute acid sulphate solutions attack several metallic sulphides and generate hydrogen sulphide. With equal surfaces exposed, such solutions in these experiments set hydrogen sulphide free at least four times as rapidly from zinc blende as from pyrite or chalcopyrite, and about twenty-five times as rapidly from pyrrhotite as from zinc blende. With pyrite and chalcopyrite the amount of hydrogen sulphide generated is small and the quantities determined may represent the end points of titration, for hydrogen sulphide was not identified as a product of the reaction. Doubtless sphalerite containing considerable iron sulphide will react more readily with acid than pure zinc sulphide. The quantity of hydrogen sulphide generated with galena, sphalerite, and pyrrhotite was sufficiently great, perhaps, to give the results a quantitative value.

These experiments were carried on with pure minerals that had been carefully examined. Minerals so pure are seldom found in large bodies of sulphide ores, where the sulphides generally occur in more or less intimate association. Gottschalk and Buehler have recently shown that in such mixtures weak batteries are formed and that the oxidation and solution of the mineral with the lowest potential will be increased while the solution of the mineral which is higher in the series will be retarded. There is no reason to suppose that the order of solution in an oxidizing environment like that in which the experiments of Gottschalk and Buehler were carried on would correspond closely to the order of attack in a reducing environment like that which existed under the conditions of Mr. Wells's experiments. Yet the associations of the sulphides may affect the rate of their solution in the reducing zone also. Consequently the rate of attack of acid sulphate solutions on various sulphide ores in the reducing zone can not be accurately stated. Possibly each association is a problem in itself. Where one of the metallic sulphides greatly predominates,

however, it should not be supposed that a high potential would greatly retard its attack by acid in the reducing environment which is assumed to exist where the secondary sulphides are precipitated.

The laboratory experiments and geologic observations indicate that pyrrhotite is attacked very readily by acidic solutions, at least where it constitutes a considerable part of the ore. The reaction with sphalerite was less rapid than with pyrrhotite but more rapid than with pyrite and chalcopyrite. Here, too, field observations support the conclusions based on the laboratory experiments available. Describing the chalcocitization of sphalerite at Morenci, Lindgren¹ says: "Pyrite apparently does not precipitate Cu_2S or CuS while zinc blende is present." Weed notes also that sphalerite is present in some of the primary ores at Butte, but that it is absent in the enriched chalcocite ores.² The latter, however, contain pyrite. In a recent paper by Irving and Bancroft³ on the deposits of Lake City, Colo., the precipitation of secondary minerals on sphalerite from downward-moving sulphate solutions is emphasized.

The data available seem therefore to indicate that in a large number of deposits at least the action of dilute sulphuric acid in the absence of air on the following sulphides is probably in the same order as that indicated by the experiments of Mr. Wells, viz, (1) pyrrhotite, (2) zinc blende, (3) pyrite and chalcopyrite.

COMPOSITION OF THE PRIMARY ORE AS A FACTOR DETERMINING THE VERTICAL EXTENT OF THE SECONDARY SULPHIDE ZONE.

S. F. Emmons and others have emphasized the fact that the vertical extent of the secondary sulphide zone depends principally on the amount of fracturing of the primary ore body and the size, continuity, and character of the fractures. The course of such fractures determines the course of descending waters and the size, character, and continuity of open spaces control the rates at which the solutions descend.

In their descent the metal-bearing solutions react on the walls of the watercourses, and these reactions produce changes of chemical equilibria and deposition of certain metals. These changes depend not only on the rate at which the solutions descend but also on the chemical environment through which they pass. In limestone or in calcite gangue the downward migration of copper would be delayed at least temporarily by the formation of carbonates (see p. 98) and calcite would quickly drive gold from acid solutions in which it was held dissolved as chloride.

¹ Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 183.

² Weed, W. H., Geology and ore deposits of the Butte district, Montana: Prof. Paper U. S. Geol. Survey No. 74, 1912, p. 78.

³ Irving, J. D., and Bancroft, Howland, Geology and ore deposits near Lake City, Colo.: Bull. U. S. Geol. Survey No. 478, 1911, pp. 64-65.

As already stated, dilute acid sulphate waters dissolve some pyrrhotite more rapidly than sphalerite and some sphalerite more rapidly than pyrite and chalcopyrite. The action on pyrrhotite and sphalerite is attended by the liberation of hydrogen sulphide, which precipitates several of the metals in acid solution. Under similar conditions, because the reaction is brought near to completion more quickly, the vertical extent of the zones of secondary ores should be less in primary ores which carry abundant pyrrhotite than in ores of pyrite and chalcopyrite which contain no pyrrhotite, and although such secondary zones might be richer they would not extend so deep.

The attack of acid sulphate solutions on sphalerite is probably less vigorous than on pyrrhotite but more vigorous than the action on pyrite and chalcopyrite; consequently deposits that carry sphalerite should have secondary zones which are not so extensive vertically as those of deposits that contain pyrite and chalcopyrite with neither sphalerite nor pyrrhotite. Briefly stated, the vertical extent of the secondary sulphide zones should vary inversely with the rate at which the descending acid sulphate solutions attack the primary sulphides.

The data at present available do not cover a wide range of conditions and combinations, and the relations above indicated may have but little quantitative value, because deposits and minerals are not equally permeable, postmineral fractures are not equally spaced, equal surfaces of the primary minerals are not exposed, all deposits have not been equally eroded, and the temperatures prevailing are not the same. But notwithstanding these differences in the physical environment and geologic history of the deposits in different mining districts, I believe that the secondary sulphide zones of many deposits show relationships that depend on the composition of the primary ore and that may be rationally explained when inspected in the light of these chemical relations.

Principal mineral combinations of three groups of copper deposits.

1	2	3
Pyrrhotite ores with pyrite and chalcopyrite, with or without zinc blende.	Pyritic ore with sphalerite and chalcopyrite, and with little or no pyrrhotite.	Pyritic chalcopyrite ores, with little or no pyrrhotite or zinc blende.
Ducktown, Tenn. Gossan lead, Va. and N. C. Ely, Vt. Santiago de Cuba. Encampment, Wyo. Grants Pass, Oreg. Bingham, Utah (in part). Sudbury, Ontario.	Morenci, Ariz. Santa Rita, N. Mex. (in part). Shasta County, Cal. Velardeña, Mexico. Jerome, Ariz. Cananea, Mexico.	Butte, Mont. (in part). Bisbee, Ariz. Globe, Ariz. Miami, Ariz. Ray, Ariz.

In the foregoing table certain deposits have been so grouped that three classes of copper ores may be inspected to ascertain whether the secondary chalcocite zones have a greater vertical extent in pyrrhotite deposits, in sphalerite deposits, or in copper deposits

that contain little or no sphalerite or pyrrhotite. Those in the first column contain considerable pyrrhotite; all except one of them are known to have comparatively shallow chalcocite zones; in general the lower limit of chalcocite is from 50 to 250 feet below the present surface. These deposits are said to be comparatively tight and relatively impervious to the downward migration of mineral waters; consequently they do not afford examples ideal for comparison. Nevertheless I can find no example of a deposit that carries abundant pyrrhotite in which secondary sulphides are shown to have been deposited at great depths.

On comparing the deposits of column 1 with those of column 3 it is clearly apparent that the chalcocite zones in the latter are of much greater vertical extent; indeed, they include the deepest chalcocite zones that have been developed. In several of the deposits of column 3 chalcocite extends to depths ranging from 1,000 to nearly 1,500 feet below the surface. It is found at still greater depths at Butte, Mont., but an increasing trend of opinion held by those most familiar with these deposits indicates that the chalcocite of the lower levels of the Butte mines is primary. In some of the deposits of Arizona the secondary zones are very extensive vertically owing to the great distance to the zone of saturation. Undoubtedly some of the deposits of column 3 are much more highly fractured than some of those of column 1, consequently these examples are likewise not ideal for comparison. Yet the fact that none of the deposits with deep chalcocite are known to carry appreciable pyrrhotite appears to be significant.

The deposits of column 2 have chalcocite zones which in general are of greater vertical extent than those of column 1 and less than those of column 3, but possibly the differences are too slight to give the figures much significance. It is a fact familiar to all, however, that rich silver ores frequently give way in depth to primary ores containing abundant sphalerite, the contact zone being at some places comparatively narrow.

From the comparison of the several groups of deposits investigated, it is concluded that with approximately similar temperature, rainfall, erosion, head, permeability, and other conditions, the vertical extent of the secondary sulphide zone depends principally on the character and extent of fracturing in the primary ore bodies, but the vertical distribution of the secondary sulphides shows a relation also to the mineral composition of the primary ore. In general, ores containing abundant pyrrhotite are not enriched to depths so great as those containing pyrite and chalcopyrite but little or no pyrrhotite. The influence of zinc blende and of a small proportion of pyrrhotite can not yet be positively stated.

SOME CHEMICAL RELATIONS AND MINERALS OF COPPER.

PRINCIPAL COPPER MINERALS.

The names and the chemical composition of the principal copper minerals are given below:

Copper.....	Cu.
Chalcanthite.....	$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$.
Pisanite.....	$(\text{Cu}, \text{Fe})\text{SO}_4 \cdot 7\text{H}_2\text{O}$.
Brochantite.....	$\text{Cu}_4\text{SO}_4(\text{OH})_6$ or $4\text{CuO} \cdot \text{SO}_3 \cdot 3\text{H}_2\text{O}$.
Nantokite.....	CuCl .
Atacamite.....	$\text{Cu}_2\text{Cl}(\text{OH})_2$ or $\text{CuCl}_2 \cdot 3\text{Cu}(\text{OH})_2$.
Malachite.....	$\text{Cu}_2(\text{OH})_2\text{CO}_3$ or $2\text{CuO} \cdot \text{CO}_2 \cdot \text{H}_2\text{O}$.
Azurite.....	$\text{Cu}_3(\text{OH})_2(\text{CO}_3)_2$ or $3\text{CuO} \cdot 2\text{CO}_2 \cdot \text{H}_2\text{O}$.
Chrysocolla.....	$\text{CuSiO}_3 \cdot 2\text{H}_2\text{O}$ or $\text{CuO} \cdot \text{SiO}_2 \cdot 2\text{H}_2\text{O}$.
Diopside.....	CuH_2SiO_4 or $\text{CuO} \cdot \text{SiO}_2 \cdot \text{H}_2\text{O}$.
Cuprite.....	Cu_2O .
Tenorite.....	CuO .
Copper pitch ore. ¹	
Chalcocite.....	Cu_2S .
Covellite.....	CuS .
Bornite ²	Cu_5FeS_4 .
Chalcopyrite.....	CuFeS_2 or $\text{Cu}_2\text{S} \cdot \text{Fe}_2\text{S}_3$.
Enargite.....	Cu_3AsS_4 or $3\text{Cu}_2\text{S} \cdot \text{As}_2\text{S}_3$.
Tetrahedrite.....	$\text{Cu}_5\text{Sb}_2\text{S}_7$ or $4\text{Cu}_2\text{S} \cdot \text{Sb}_2\text{S}_3$.
Tennantite.....	$\text{Cu}_3\text{As}_2\text{S}_7$ or $4\text{Cu}_2\text{S} \cdot \text{As}_2\text{S}_3$.
Famatinite.....	Cu_3SbS_4 or $3\text{Cu}_2\text{S} \cdot \text{Sb}_2\text{S}_3$.

SOLUBILITY OF SOME COPPER COMPOUNDS.³

At 20° C. a liter of water dissolves 172 grams⁴ CuSO_4 . At 20° C. a liter of water dissolves 435 grams CuCl_2 . At 15° to 16° C. a liter of water containing 16.66 grams HCl dissolves 61.59 grams CuCl .

NATURE AND RELATIONS OF THE COPPER MINERALS.

Copper, silver, and gold belong chemically to the same family; the three elements occupy exclusively the right side of the second column of the table of the periodic system and are somewhat closely affiliated. They stand apart as metals in the concentration of which the processes of sulphide enrichment are most clearly expressed. They are dissolved more or less readily in an oxidizing sulphate or chloride environment and are readily precipitated from acid waters by reactions in the sulphide environment where oxygen is excluded.

The mineral waters in the oxidizing zones of sulphide deposits are acid sulphate and ferric sulphate solutions. In the presence of oxygen such solutions dissolve copper very readily, and in contact with

¹ A complex hydrated oxide.

² Formula as established by B. J. Harrington (Am. Jour. Sci., 4th ser., vol. 16, 1903, p. 151). The older, commonly accepted formula is Cu_5FeS_4 , also written $\text{Cu}_2\text{S} \cdot \text{CuS} \cdot \text{FeS}$, or $3\text{Cu}_2\text{S} \cdot \text{Fe}_2\text{S}_3$.

³ Seidell, Atherton, Solubilities of inorganic and organic substances, D. Van Nostrand Co., New York, 1907.

⁴ For the solubility of hydrated copper sulphate see p. 53.

copper compounds such a system will contain also copper sulphate. The copper sulphate in solution reacts with carbonates or with acid carbonate in solution, precipitating copper carbonate. If chlorides are abundant, copper chlorides may form. Cupric chloride is readily soluble in water; cuprous chloride oxidizes to form oxychlorides. In moist countries both chlorides are unstable. In arid countries copper chloride may accumulate as atacamite. The sulphates chalcantite and brochantite also may be precipitated, and the basic sulphate brochantite once formed is stable. The silicates of copper are probably formed by copper-bearing solutions reacting on silicic acid, which, as shown by analyses, is commonly dissolved in mine waters. Native copper, cuprite, and tenorite are formed by the reduction or oxidation of various copper compounds. Frequently such changes are pseudomorphic after an older mineral. All the copper minerals mentioned above are formed in the main in the oxidized or oxidizing zone, and in sulphide ore deposits their occurrence below the oxidizing zone is exceptional. None of them are known to form in depth by deposition from hot ascending alkaline solutions.

Below the oxidizing zone, where air is excluded, copper is precipitated as sulphides; chalcocite, covellite, bornite, chalcopyrite, and possibly some of the more complex antimony and arsenic compounds are formed by these processes. Precipitation may be brought about by chemical interchange with pyrite, chalcopyrite, pyrrhotite, zinc blende, galena, and probably with some other sulphides, the process being mainly metasomatic replacement. The copper sulphides are precipitated also by hydrogen sulphide, which may be generated by attack of acid sulphate solutions on several of these sulphides. At ordinary temperatures only 3.51×10^{-6} mols of copper sulphide dissolves in a liter of water. In the reducing environment the copper sulphides are stable. They are insoluble even in hot concentrated acid sulphate solutions if a slight trace of hydrogen sulphide is present.¹

Iron sulphide dissolves in acid, however, and it should not be supposed that the double sulphides of iron and copper would be precipitated from acid solutions which contained much copper. But as the solutions descend they lose acidity, and copper sulphide is precipitated at the expense of iron sulphide, the iron going into solution. A decrease in acidity, a decrease in copper, and an increase of iron in solution bring about a state of equilibrium which is increasingly favorable to the precipitation of double sulphides, such as chalcopyrite and bornite.²

In the oxidizing zone copper is much more soluble than gold, and, unlike gold, it may be dissolved in the absence of chlorides in sul-

¹ Allen, E. T., oral communication.

² Wells, R. C., *The fractional precipitation of sulphides*: Econ. Geology, vol. 5, 1910, pp. 12-13.

phate solutions. Thus many deposits which contain both copper and gold show a distinct segregation of gold near the surface, while copper ores with subordinate gold are found in depth. The Highland Boy mine, at Bingham, Utah; the United Verde mine, at Jerome, Ariz.; and the Mount Morgan mine, in Australia, were operated first as gold mines and subsequently developed large bodies of copper-gold ores. In two of these mines the gold has probably not been dissolved to any great extent; in one, the Mount Morgan mine, the solution of gold is clearly indicated. Even where the conditions for the solution of gold are most favorable, however, it is probably precipitated mainly in the upper part of the chalcocite zone. It would not remain in solutions that contain much ferrous sulphate, and chalcocitization is doubtless attended by the generation of abundant ferrous sulphate.

Silver, like copper, dissolves somewhat readily in an acid sulphate environment, especially if ferric sulphate is present. Silver sulphide is not so soluble as copper sulphide, however (see p. 59), and in the presence of chlorides its downward migration is delayed by its precipitation as cerargyrite, or in the presence of ferrous sulphate or in contact with several sulphides and gangue minerals native silver is deposited. Some of the great copper lodes of Butte, Mont., were worked for silver to depths from 200 to 400 feet below the surface, where the deposits changed to rich copper ore.¹ Like gold, silver would be driven from sulphate solutions in an environment where chalcocite forms. Its sulphide is even less soluble than copper sulphide and in depth would be precipitated as argentite. The rich narrow chalcocite zones at Ducktown, Tenn., contained considerable silver, although the primary pyrrhotite ore is only slightly argentiferous. In the north vein, Mass II, at Rio Tinto, Spain,² both gold and silver were concentrated in a thin layer just above the zone of copper and iron sulphides.

As already stated, both gold and silver are precipitated from dilute solutions by ferrous sulphate, but copper sulphate and ferrous sulphate may exist in the same solution without precipitation of copper. It is reasonable to suppose that native silver as well as gold may be precipitated with chalcocite, but it is not so likely that under these conditions native copper and chalcocite would be precipitated simultaneously.

The rate at which certain sulphides react with acid to generate hydrogen sulphide and the tendency of certain ores to delay the downward migration of copper has already been discussed (p. 59).

¹ Emmons, S. F., The secondary enrichment of ore deposits, in Pošepný, Franz, The genesis of ore deposits, 1902, pp. 442-443.

² Vogt, J. H. L., Problems in the geology of ore deposits, in Pošepný, Franz, op. cit., p. 676.

The precipitation of gold and silver, if any were held in the copper sulphate solution, would be even more rapid.

Carbonates react with solutions of acid sulphate even more rapidly than pyrrhotite and likewise tend to delay the downward migration of copper, gold, and silver. If there is much lime carbonate in the gangue of the ore or in the wall rock, the downward migration of metallic sulphates may be checked or even inhibited. As stated by Bard,¹ chalcocitization is seldom extensive in carbonate rocks, because the copper is precipitated as carbonate by reaction with calcite. To this there are some exceptions, and, appreciating these, Bard notes that the precipitation of some copper carbonate on the limestone may inhibit further action and insulate the passages from reaction with the descending solutions. Under such conditions copper sulphate could descend through carbonate rocks to considerable depths, where it could be precipitated by iron sulphide or by hydrogen sulphide if any were generated by the action of acid on sulphides or as copper carbonate by reactions with limestone.

In some districts, however, the primary mineralization of limestone is attended by extensive silicification. If carbonate has been removed, it would of course be no longer effective. The silicification of limestone at Bisbee, Ariz., has doubtless removed much of the carbonate in the region of the ore bodies.

A gangue of siderite, dolomite, or other carbonates would react with acid sulphate solutions and tend to neutralize them and to precipitate gold, silver, or copper, but the reaction would be somewhat less rapid than with calcite.

OCCURRENCE OF THE COPPER MINERALS.

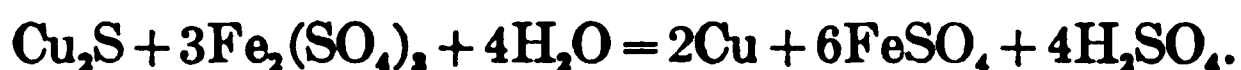
Native copper occurs in the Lake Superior district and in zeolitic lodes elsewhere as the principal primary copper mineral. In the sulphide ores of the Cordillera of North America native copper is confined to the upper zone of the ore bodies and is clearly secondary. It is formed in many places by the reduction of cuprite and is frequently found, with copper oxides, directly above the zone of secondary chalcocite ores. The following reactions have been suggested but not proved:



At Cananea, Mexico, at Cashin, Colo., and at many other places tabular masses of native copper cut the decomposed oxidized ore, suggesting the possibility that it has altered directly from chalcocite. At Morenci, Ariz., it is associated with cuprite, as a rule in the upper

¹ Bard, D. C., Absence of secondary copper sulphide enrichment in calcite gangues: *Econ. Geology*, vol. 5, 1910, p. 59.

limit of the chalcocite zone. In the Williams vein, Arizona Central mine, in this district,¹ 200 feet below the surface, a vein of solid copper was found in sericitized porphyry. The vein formed a sheet of copper, in places 8 inches thick, standing nearly vertical. It had in places a fibrous structure, perpendicular to the plane of the vein, such as occasionally is exhibited by the chalcocite seams, of which it is believed to be a pseudomorphic development. In one specimen, according to Lindgren, two sheets of copper were found separated by sooty chalcocite. In view of these relations it appears that copper may form directly from chalcocite without the intermediary stage of oxidation to cuprite. Lindgren suggests this reaction:



Native copper was abundant above the third level of the Copper Queen ore body at Bisbee, Ariz., but comparatively rare in the lower portions of the oxidized ores.² In the Calumet & Arizona mine, however, it is abundant on the 1,050-foot level. It occurs in part as incrustations of chalcocite. At Bingham, Utah,³ it is rare but has been observed. Native copper is extensively developed in the upper zones of copper deposits at Santa Rita, N. Mex. In general it is abundant from 100 to 200 feet below the surface. According to Lindgren, Graton, and Gordon,⁴ it is probably an alteration product of sulphides, but the latter appear to have been deposited in part in open spaces in the porphyry rather than as replacements of pyrite. In this district and also in the copper deposits of Lake Superior native copper has been found as perfect pseudomorphs after hornblende. According to Yeates,⁵ native copper in Grant County, N. Mex., is pseudomorphous after azurite. Native copper is not abundant at Butte, Mont.⁶

In view of the fact that ferrous sulphate, a reducing agent, probably accumulates at depths at which chalcocite forms, one would suppose that native copper, which is a product of reduction, might be deposited under some conditions along with chalcocite; this association is not uncommon, but may be due to subsequent oxidation and partial reduction of chalcocite to native copper. At Ducktown, Tenn., according to report, when mines that had been closed during

¹ Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 101.

² Ransome, F. L., The geology and ore deposits of the Bisbee quadrangle, Arizona: Prof. Paper U. S. Geol. Survey No. 21, 1904, p. 120.

³ Boutwell, J. M., Economic geology of the Bingham mining district, Utah: Prof. Paper U. S. Geol. Survey No. 38, 1905, p. 110.

⁴ Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: Prof. Paper U. S. Geol. Survey No. 68, 1910, p. 316.

⁵ Yeates, W. S., Pseudomorphs of native copper after azurite, from Grant County, N. Mex.: Am. Jour. Sci., 3d ser., vol. 38, 1889, pp. 405-407.

⁶ Weed, W. H., Geology and ore deposits of the Butte district, Montana: Prof. Paper U. S. Geol. Survey No. 74, 1912, p. 80.

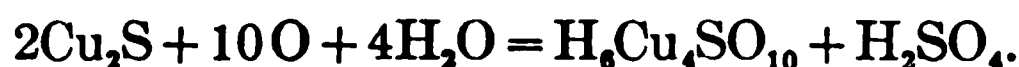
the Civil War were reopened masses of native copper were found hanging to some of the timbers.¹

Chalcanthite, blue vitriol, $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, is frequently present in the oxidized zones as efflorescences or stalactites on open fissures, or as veinlets filling small crevices above the upper limit of the zone of secondary sulphides. At Ducktown, Tenn., it is abundant also in the chalcocite zone. It rarely forms far below the top of the chalcocite zone, except on surfaces of openings made by mining operations. Locally it is an ore of some importance. At Butte, Mont., according to Weed,² it coats rock fragments in old stopes, in places so abundantly that it has been found profitable to collect it from time to time. In the Silverbow mine pure chalcanthite is so abundant as to almost fill some of the old drifts. Beautiful stalactites and shapes imitating organ pipes are developed. Weed states that copper sulphate is carried by the moisture of the atmosphere circulating in mine openings.³

Pisanite, $(\text{CuFe})\text{SO}_4 \cdot 7\text{H}_2\text{O}$, is a rare sulphate of copper and iron. Large and beautiful specimens were found in copper deposits at Bingham, Utah.⁴ At Butte, Mont., stalactites occur, usually in deserted drifts.⁵

Brochantite, $\text{H}_6\text{Cu}_4\text{SO}_{10}$, a basic sulphate of copper, has been identified at only a few places. It is of common occurrence in the ores of the Clifton-Morenci district, Arizona, where, according to Lindgren,⁶ it is intergrown with malachite, which effectively masks its presence in hand specimens. In the Shannon mine, near the surface, in porphyry, it constitutes a rich ore body. Ransome noted it also in sections from the oxidized zone at Bisbee, Ariz. In all its occurrences it is probably a deposit from oxidizing waters.

Sullivan⁷ obtained a substance of the composition of brochantite by treating silicates with copper sulphate solutions. Lindgren⁸ states that brochantite may form directly by the oxidation of chalcocite according to the following reaction:



Atacamite and nantokite.—Atacamite, $\text{CuCl}_2 \cdot 3\text{Cu}(\text{OH})_2$, the oxy-chloride of copper, and nantokite, CuCl , cuprous chloride, are com-

¹ Edwards, W. F., Discussion of papers by H. A. Lee, on "Gases in metalliferous mines": Proc. Colorado Sci. Soc., vol. 7, 1904, p. 183.

² Weed, W. H., Geology and ore deposits of the Butte district, Montana: Prof. Paper U. S. Geol. Survey No. 74, 1912, p. 81.

³ Idem, p. 99.

⁴ Boutwell, J. M., Economic geology of the Bingham mining district, Utah: Prof. Paper U. S. Geol. Survey No. 38, 1905, p. 111.

⁵ Weed, W. H., op. cit., p. 82.

⁶ Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 119.

⁷ Sullivan, E. C., The interaction between minerals and water solutions: Bull. U. S. Geol. Survey No. 312, 1907, p. 61.

⁸ Op. cit., p. 188.

paratively rare secondary copper minerals. They are probably formed in the oxidized zones, but on account of their solubility in natural waters they do not generally accumulate.

Since cuprous chloride is comparatively less soluble in water, it would be supposed that nantokite would be fixed more readily than the cupric salt atacamite. On exposure to the air, however, the cuprous chloride is oxidized to form atacamite. Such is said to be the genesis of some atacamite of Chile. In the United States the natural chlorides of copper are almost unknown.

Malachite, $(\text{CuOH})_2\text{CO}_3$, a basic cupric carbonate, is abundant in the oxidized zones of many cupriferous deposits and is most abundant in deposits that are inclosed in limestone. It was present in considerable quantity in the superficial portions of copper deposits at Bingham, Utah,¹ where it occurs as globular masses and also as bands equivalent to parts of certain rock strata. It also forms envelopes about sulphides and oxides. In the Old Dominion mine at Globe, Ariz., according to Ransome,² malachite is conspicuously developed as veinlets in quartzite and has locally replaced the quartzite. Malachite is present almost universally in the oxidized zones of sulphide deposits and in some of them it persists in the outcrop. Its association with limonite in the gossan has encouraged deep development in many copper districts. It is unknown as a primary ore in deposits formed by thermal waters.

If copper sulphate waters should mingle with acid carbonate waters the following reaction³ would probably take place:



Acid waters attacking limestone would form malachite according to the following reaction:



Solutions of iron sulphate and copper sulphate react with limestone and deposit limonite and malachite simultaneously.⁴

Azurite, $2\text{CuCO}_3 \cdot \text{Cu}(\text{OH})_2$, like malachite, is a basic cupric carbonate. So far as known, it is not formed by ascending thermal waters. It is very much less abundant than malachite, but in some deposits in limestone, as at Bisbee, Ariz., it is plentiful. Kemp⁵ suggests the following reaction with copper sulphate and acid carbonate solutions:



¹ Boutwell, J. M., Economic geology of the Bingham mining district, Utah: Prof. Paper U. S. Geol. Survey No. 38, 1905, p. 107.

² Ransome, F. L., Geology of the Globe copper district, Arizona: Prof. Paper U. S. Geol. Survey No. 12, 1903, p. 122.

³ Kemp, J. F., Secondary enrichment in ore deposits of copper: Econ. Geology, vol. 1, 1906, p. 24.

⁴ Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1906, pp. 189-190.

At Morenci it is frequently associated with kaolin¹ and is generally one of the last minerals to form.

In limestone azurite may be formed according to the following reaction:



Chrysocolla, the bluish-green hydrous copper silicate $\text{CuOH}_2\text{SiO}_3$, forms rather abundantly in the outcrops and near the surface of some copper deposits; in others it is rare or absent. It is a common mineral also in the oxidized zone of some silver and gold mines. Although widely distributed in some lodes, it occurs at most places only in small bodies. It is frequently associated with malachite and azurite and is not known as a deposit of ascending hot waters. At Globe, Ariz.,² chrysocolla replaces dacitic tuff. In this district it is older than malachite where the two minerals are together and it forms at greater depth than malachite. It is an ore mineral in several other deposits of the Southwest, where it is mined with copper oxides and carbonates. At Bisbee it seems never to have been abundant, but in the Calumet & Arizona mine it forms thin shells about kernels of cuprite, native copper, and brochantite and is in turn enveloped by malachite and calcite.³ At Butte, Mont.,⁴ it is found in the country rock near the veins. At Cripple Creek⁵ chrysocolla is an oxidation product of tetrahedrite.

There is no record of the synthesis of chrysocolla in the laboratory. Kemp⁶ has suggested that it results from gelatinizing silica and solutions of copper sulphate:



It appears that the abundant carbonate is not uniformly a necessary condition for its genesis, since in the Morenci district, Arizona,⁷ it is more abundant in the ores in porphyry and in granite than in the ores in limestone. In some deposits in porphyry it is of commercial value. An interesting occurrence of highly auriferous chrysocolla is that of the Original Bullfrog mine in Nevada. If in the reaction suggested by Kemp ferrous acid carbonate were present in place of

¹ Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 118.

² Ransome, F. L., Geology of the Globe copper district, Arizona: Prof. Paper U. S. Geol. Survey No. 12, 1903, p. 123.

³ Ransome, F. L., The geology and ore deposits of the Bisbee quadrangle, Arizona: Prof. Paper U. S. Geol. Survey No. 21, 1904, p. 126.

⁴ Weed, W. H., Emmons, S. F., and Tower, G. W., Butte special folio (No. 38), Geol. Atlas U. S., U. S. Geol. Survey, 1897, p. 6.

⁵ Lindgren, Waldemar, and Ransome, F. L., Geology and gold deposits of the Cripple Creek district, Colorado: Prof. Paper U. S. Geol. Survey No. 54, 1906, p. 129.

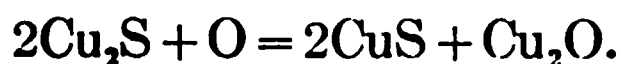
⁶ Kemp, J. F., Secondary enrichment in ore deposits of copper: Econ. Geology, vol. 1, 1906, pp. 24-25.

⁷ Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 112.

that of lime, ferrous sulphate would form instead of calcium sulphate. Minute quantities of ferrous sulphate drive gold from solutions in which it is dissolved as chloride. Possibly the free gold of chrysocolla was precipitated by ferrous sulphate.

Diopside, H_2CuSiO_4 , or $\text{H}_2\text{O} \cdot \text{CuO} \cdot \text{SiO}_2$, like chrysocolla, is a secondary copper silicate. It is characteristically formed in the zone of oxidation and is unknown as a deposit from hot ascending waters. It is known in only a few places in the United States, among them Morenci, Ariz.,¹ where it is associated with chrysocolla in limestone.

Cuprite, Cu_2O , is a common mineral of the oxidized zones of deposits of copper sulphides and is probably secondary in all its occurrences. It is an important ore mineral at Bisbee, Ariz., where, according to Ransome,² it is found in an impure earthy condition mixed with limonite and ferruginous clays or in crystalline masses associated with native copper. The latter occurrence is particularly characteristic of the deeper oxidized zones in the vicinity of chalcocite and other sulphides. In the Calumet & Arizona mine cuprite is found in large crystalline masses. On the 950-foot level it occurs in bunches in earthy ore, penetrated by dendritic masses of metallic copper and spotted with little vugs of acicular malachite. It is abundant at Morenci, Ariz., at Cananea, Sonora, and in other western districts. At Morenci, according to Lindgren,³ it occurs normally at the upper limit of the chalcocite zone as a product of decomposition of chalcocite. Similar relations are shown at Cananea. At Santa Rita, N. Mex., abundant cuprite and native copper fill fissures in the oxidized zone and presumably are secondary in the main after chalcocite. At Butte, Mont., where it is sparingly developed and is not important commercially,⁴ it generally contains masses of native copper, the line of contact between them being indistinct.⁵ According to Boutwell⁶ cuprite is not abundant at Bingham, Utah, but small grains covered with malachite were noted in brown altered limestone of the Commercial mine. Cuprite is present in the upper portion of the rich secondary ore at Ducktown, Tenn., and in other copper deposits of the southern Appalachians. The mode of its derivation from chalcocite is stated by Lindgren as follows:⁷



¹ Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 111.

Ransome, F. L., The geology and ore deposits of the Bisbee quadrangle, Arizona: Prof. Paper U. S. Geol. Survey No. 21, 1904, p. 128.

³ Lindgren, Waldemar, *op. cit.*, p. 106.

⁴ Weed, W. H., Geology and ore deposits of the Butte district, Montana: Prof. Paper U. S. Geol. Survey No. 74, 1912, p. 80.

⁵ Weed, W. H., Emmons, S. F., and Tower, G. W., Butte special folio (No. 38), Geol. Atlas U. S., U. S. Geol. Survey, 1897, p. 6.

⁶ Boutwell, J. M., Economic geology of the Bingham mining district, Utah: Prof. Paper U. S. Geol. Survey No. 38, 1905, p. 109.

⁷ Lindgren, Waldemar, *op. cit.*, p. 126.

Lindgren considers it improbable that ferrous sulphate reduces cupric sulphate to precipitate cuprous oxide, since cupric sulphate and ferrous sulphate appear to mix in all proportions without reaction.

Tenorite, CuO , the crystalline form of the black oxide of copper, is much less abundant than cuprite. The earthy, sooty variety, known as melaconite, is said to be present at Butte, Mont., where it is associated with cuprite and native copper and forms dark rims about cuprite.¹ According to Boutwell² scales of black copper oxide with metallic luster occur with chalcocite in ores of Bingham, Utah. At Bisbee³ melaconite is found in soft clayey ores on the 1,000-foot level of the Lowell mine. Apparently it is now being deposited along with wad near the 850-foot level of the Calumet & Arizona mine. At Ducktown, Tenn., much of the so-called black copper ore has proved to be sooty chalcocite.

Copper pitch ore is a secondary material of complex character and somewhat uncertain composition. A sample from the Detroit mine in the Morenci district, Arizona,⁴ analyzed by Hillebrand, showed oxides of copper, zinc, and manganese, with considerable water and silica. Material that is probably of a similar nature is found at Bisbee and at Courtland, Ariz., and on the Ida, Montgomery, and Amazon claims⁵ at Butte, Mont.

Chalcocite, Cu_2S , copper glance, is economically the most important copper mineral. In 1906, according to Graton,⁶ 47 per cent of the copper produced in the United States was derived from chalcocite ores. In most of its occurrences chalcocite is clearly of secondary origin, for it replaces other minerals metasomatically or occurs as veinlets in small cracks in the primary ore. Well-authenticated examples are known of its replacement of pyrite, zinc blende, and galena. In many deposits now worked in which chalcocite is the principal mineral exploration extends into the lower-grade primary sulphide ore, which generally consists of chalcopyrite, pyrite, and other minerals without chalcocite.

Examples indicating replacement of pyrite by chalcocite are numerous. At Morenci, Ariz., according to Lindgren,⁷ most of the ore bodies owe their origin to this process. Lindgren writes:

By chalcocitization the massive veins of pyrite become transformed into solid masses of black dull chalcocite, while the sericitized porphyry becomes filled with

¹ Weed, W. H., Emmons, S. F., and Tower, G. W., Butte special folio (No. 38), Geol. Atlas U. S., U. S. Geol. Survey, 1897, p. 6.

² Boutwell, J. M., Economic geology of the Bingham mining district, Utah: Prof. Paper U. S. Geol. Survey No. 38, 1905, p. 109.

³ Ransome, F. L., The geology and ore deposits of the Bisbee quadrangle, Arizona: Prof. Paper U. S. Geol. Survey No. 21, 1904, p. 128.

⁴ Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 114.

⁵ Weed, W. H., Geology and ore deposits of the Butte district, Montana: Prof. Paper U. S. Geol. Survey No. 74, 1912, p. 81.

⁶ Graton, L. C., Copper: Mineral Resources U. S. for 1906, U. S. Geol. Survey, 1907, p. 410.

⁷ Lindgren, Waldemar, op. cit., p. 185.

grains and little seams of the same mineral. The first constitutes high-grade ores, the second the low-grade. A residue of pyrite, not yet acted upon, is nearly always present. Thus a vein of massive sooty material cutting the shale in the Montezuma mine contained 96 per cent Cu_2S and 2.4 per cent FeS_2 , and pyrite may be easily seen in nearly every specimen of low-grade porphyry ore. The pyrite first becomes coated with a black stain; in a more advanced stage the chalcocite penetrates the pyrite on cracks and fissures in all directions; finally it almost entirely replaces it. * * * Kaolin gouge always accompanies chalcocite when occurring as massive veins; in the chalcocitized porphyry the process is nearly always attended by a formation of a little brownish kaolin, together with microcrystalline quartz or more often chalcedony; these minerals encircle the pyrite or traverse the chalcocite as minute veinlets, distinctly later than the alteration of the porphyry to sericite and pyrite. Sericite does not form during chalcocitization; on the contrary, the kaolin is formed at the expense of that mineral. * * * The transition from chalcocite to unaltered pyrite at the lower limit of the zone is remarkably sudden. Usually a change takes place within 25 feet, sometimes within 10 feet, from rich chalcocite ore to pyrite with one-half to 1 per cent copper. Chalcopyrite is rarely found as a secondary mineral but has been observed as small grains inclosed in chalcocite veinlets.

At Bingham, Utah, according to Boutwell,¹ chalcocite incloses pyrite and chalcopyrite. At the Snowstorm and Park mines, in the Cœur d'Alene district, Idaho, chalcocite and bornite ore are disseminated in quartzite. At the Park mine chalcocite has formed on pyrite and chalcopyrite.² In the Bisbee district, according to Ransome, chalcocite occurs as veinlets in and envelopes around grains of pyrite. Limestone altered to white claylike material is streaked with veinlets of chalcocite and speckled with native copper. Some solid, compact chalcocite is associated with bornite.³ Examples of replacement of pyrite by chalcocite could be multiplied to include occurrences from nearly every important district of copper sulphide ores in the United States.

In the copper deposits of Butte, Mont., which are perhaps the largest in the world, chalcocite is an important ore mineral. The bulk of the ore is altered "granite" with disseminated grains and veinlets of chalcocite intergrown with pyrite or replacing that mineral completely. Distinct crystals are rare. In this district the history of the vein formation is exceedingly involved, and at least three periods of mineralization are recognized. The great chalcocite bonanzas in the upper levels at Butte were regarded by S. F. Emons, W. H. Weed, H. V. Winchell, and others as secondary, and no other interpretation appears to be warranted by their occurrence and relations. More recently, however, masses of ore containing chalcocite have been found as deep as 2,800 feet below the surface, and Reno

¹ Boutwell, J. M., Economic geology of the Bingham mining district, Utah: Prof. Paper U. S. Geol. Survey No. 38, 1905, pp. 221-222.

² Ransome, F. L., and Calkins, F. C., The geology and ore deposits of the Cœur d'Alene district, Idaho. Prof. Paper U. S. Geol. Survey No. 62, 1908, p. 91.

³ Ransome, F. L., The geology and ore deposits of the Bisbee quadrangle, Arizona: Prof. Paper U. S. Geol. Survey No. 21, 1904, pp. 123-124.

Sales¹ is of the opinion that a portion of the massive deep-seated chalcocite at Butte is of primary origin. The studies of polished surfaces examined microscopically by Simpson² of ore from the 2,000-foot level showed massive pyrite surrounding, in the plane of the section, small and apparently isolated flakes of chalcocite. A veinlet of ore from the 1,000-foot level of the Leonard mine shows isolated idiomorphic crystals of quartz and pyrite surrounded by chalcocite.³ It is not easy to account for secondary chalcocite in such surroundings.

L. C. Graton noted that chalcocite is found as deep as 970 feet in the Bully Hill mine, Shasta County, Cal., where it seems to be below the zone of secondary sulphide enrichment. He says that "there is no reason to believe that it is secondary."⁴

According to Lewis,⁵ chalcocite is the original and essential ore of the Rocky Hill mine, in New Jersey. Likewise the chalcocite in the region of Christiania, Norway, is regarded by V. M. Goldschmidt⁶ as in part a primary mineral.

The copper lodes of the Virgilina district, in Virginia and North Carolina, described by Laney,⁷ are of peculiar interest in this connection. The country is an area of schists and gneisses intruded by granite and diabase. The deposits are fissure veins. The level of ground water is 50 to 75 feet below the surface and the zone of secondary alteration does not appear to extend below 250 feet. The important mines of the district are 350 to 500 feet deep and the ore from the deepest levels contains almost as much chalcocite as bornite.⁸ The ores in the deeper levels show little secondary fracturing, and from this Graton⁹ concluded that the chalcocite is in part of primary origin. Laney subsequently worked out the paragenesis of these ores by a microscopic study of polished surfaces. Some of his sections¹⁰ show a crystallographic intergrowth of bornite and chalcocite in relations that suggest the intergrowth of quartz and feldspar in a graphic granite. It is clear that these two minerals in this ore are contemporaneous, and since the specimens were obtained from considerable depths in tight lodes it can not reasonably be supposed

¹ Sales, R. H., Discussion of paper by F. L. Ransome, on "Criteria of downward sulphide enrichment": *Econ. Geology*, vol. 5, 1910, p. 681.

² Simpson, J. F., The relation of copper to pyrite in the lean copper ores of Butte, Mont.: *Econ. Geology*, vol. 3, 1908, p. 634.

³ Weed, W. H., Geology and ore deposits of the Butte district, Montana: Prof. Paper U. S. Geol. Survey No. 74, 1912, p. 76. For Weed's final conclusions see this bulletin, p. 176.

⁴ Graton, L. C., The occurrence of copper in Shasta County, Cal.: *Bull. U. S. Geol. Survey* No. 430, 1910, pp. 104-105.

⁵ Lewis, J. V., Copper deposits of the New Jersey Triassic: *Econ. Geology*, vol. 2, 1907, p. 247.

⁶ Goldschmidt, V. M., *Die Kontaktmetamorphose im Kristianlagebiet*, 1911, p. 250.

⁷ Laney, F. B., The relation of bornite and chalcocite in the copper ores of the Virgilina district of North Carolina and Virginia: *Econ. Geology*, vol. 6, 1911, pp. 399-411.

⁸ *Idem*, p. 399.

⁹ Graton, L. C., Copper: Mineral Resources U. S. for 1907, pt. 1, U. S. Geol. Survey, 1908, p. 620.

¹⁰ Especially that figured in his Pl. VII, fig. 2, p. 406.

that the minerals were deposited by cold sulphate waters. Laney¹ concludes that—

Chalcocite is clearly of two periods—one confined to the upper portions of the vein more recent than and filling a network of minute fractures in the bornite; the other contemporaneous and intergrown, often crystallographically, with it. There is no evidence that any of the bornite is of secondary origin. It is therefore believed that in the Virgilina district the greater part of the chalcocite is a primary mineral contemporaneous with the bornite and in no way derived from it or from any other copper-bearing minerals by processes of secondary alteration.

It appears possible from these relations that under some conditions chalcocite is deposited as a primary mineral by ascending hot waters. The intergrowth of the copper sulphide in graphic-like pattern is a feature that is difficult to explain on the hypothesis of an origin from descending sulphate waters. Ascending alkaline hot solutions are generally supposed to have deposited the primary ores of nearly all the larger copper deposits. Such solutions are doubtless variable in composition. It appears probable that under conditions where the concentration of iron is low in the solutions chalcocite may form as a primary mineral instead of chalcopyrite, which is the commoner primary ore.

The chalcocite deposits in sandstone and shale which are very widely distributed in the Southwest should be mentioned here. Many of these deposits are in areas remote from igneous rocks and appear not to be related genetically to igneous processes. They have doubtless been deposited by cold waters and some of them have replaced coal or other organic material. In New Mexico,² in Colorado,³ and elsewhere, such deposits have formed where there is no evidence that a sulphide existed previously. In the "Red Beds" of Oklahoma, 10 miles northeast of Stillwater, in Payne County, according to W. A. Tarr,⁴ veinlets of chalcocite are found cutting carbonaceous material. The chalcocite and bornite deposits of the Bonanza mine of the Chitina copper belt, Alaska,⁵ probably have a similar genesis. Barite is present in several of these ore bodies, suggesting the agency of sulphate solutions. Although these deposits are not secondary in the sense that they have formed at the expense of older sulphides, the conditions under which they were formed as regards temperature, pressure, and concentration of solu-

¹ Laney, F. B., The relation of bornite and chalcocite in the copper ores of the Virgilina district of North Carolina and Virginia: *Econ. Geology*, vol. 6, 1911, p. 411.

² Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: Prof. Paper U. S. Geol. Survey No. 68, 1910, pp. 76-77.

³ Emmons, S. F., Copper in the red beds of the Colorado Plateau region: Bull. U. S. Geol. Survey No. 260, 1905, pp. 221-232. Emmons, W. H., The Cashin mine, Montrose County, Colo.: Bull. U. S. Geol. Survey No. 285, 1906, pp. 125-128. Lindgren, Waldemar, Notes on copper deposits in Chaffee, Fremont, and Jefferson counties, Colo.: Bull. U. S. Geol. Survey No. 340, 1908, pp. 157-174.

⁴ Tarr, W. A., Copper in the "Red Beds" of Oklahoma: *Econ. Geology*, vol. 5, 1910, p. 223.

⁵ Moffit, F. H., and Maddren, A. G., Mineral resources of the Kotaina-Chitina region, Alaska: Bull. U. S. Geol. Survey No. 374, 1909, pp. 80-86.

tion are probably near those which prevail in processes of sulphide enrichment.

The conditions which are assumed to exist where secondary chalcocite is precipitated have already been stated. The solutions contain copper sulphate, iron sulphate, and probably sulphuric acid. Without much doubt the iron is mainly in the ferrous state. Stokes's equations¹ indicate that ferrous salt is liberated in the reaction. Winchell² states that hematite does not form where solutions are acid, as at Butte. According to Ransome³ the formation of chalcocite at Bisbee was effected without the development of ferric oxide as a by-product. At Globe Ransome did not detect hematite or ferric hydrate in microscopic intergrowths of pyrite-chalcocite ores. Lindgren emphasizes the presence of ferrous sulphate as an attendant of processes of chalcocitization at Morenci,⁴ and this is suggested by analyses of waters from copper deposits of Ely, Nev. One of the deeper waters collected by Lawson carried 9.36 grains per gallon of ferrous sulphate and 0.4 grain per gallon of ferric sulphate.⁵

On the other hand, Kemp shows that iron oxide has formed between covellite and chalcocite in secondary ore of Copper Mountain, British Columbia,⁶ which suggests the possibility of hydrolyzation of iron sulphate—a reaction which in acid solution takes place only with the ferric salts.

Experiments in the precipitation of chalcocite have already been reviewed. None of these experiments were carried out under exactly the conditions which probably exist in the secondary sulphide zone. Stokes's experiments (p. 133) were made at a high temperature and ferrous sulphate was not introduced. In Winchell's experiments the chalcocite was formed in the presence of sulphur dioxide, which appears to occur very sparingly, if at all, in waters from most copper mines, though lately Spencer⁷ has indicated the possibility that sulphur dioxide may be formed by the attack of cupric sulphate on pyrite. Ferrous sulphate may accomplish a similar reduction, but in experiments made by Mr. F. F. Grout and myself at the University of Minnesota to test this reaction, no chalcocite has yet formed with pyrite, at the end of one year.

In the synthesis of chalcocite with pyrite, Stokes found that covellite was formed but subsequently changed to cuprous sulphide.

¹ Stokes, H. N., Experiments on the action of various solutions on pyrite and marcasite: *Econ. Geology*, vol. 2, 1907, p. 22; See also Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 183; Wells, R. C., The fractional precipitation of sulphides: *Econ. Geology*, vol. 5, 1910, p. 1.

² Winchell, H. V., The synthesis of chalcocite and its genesis at Butte, Mont.: *Eng. and Min. Jour.*, vol. 75, 1903, pp. 783-784.

³ Ransome, F. L., The geology and ore deposits of the Bisbee quadrangle, Arizona: Prof. Paper U. S. Geol. Survey No. 21, 1904, p. 157.

⁴ Lindgren, Waldemar, *op. cit.*, p. 186.

⁵ Lawson, A. C., The copper deposits of the Robinson mining district, Nevada: *Bull. Dept. Geology Univ. California*, vol. 4, 1906, p. 333.

⁶ Kemp, J. F., Secondary enrichment in ore deposits of copper: *Econ. Geology*, vol. 1, 1906, p. 16.

⁷ Spencer, A. C., Chalcocite deposition: *Jour. Washington Acad. Sci.*, vol. 3, 1913, p. 73.

(See p. 133.) There are reasons for supposing that this takes place under conditions of sulphide enrichment, the cupric sulphide changing to cuprous sulphide in the presence of cupric sulphate and ferrous sulphate. The cuprous ion has been looked for in vain in at least ten of the analyses of mine waters. On the other hand, Wells has shown that the cuprous ion probably does exist in exceedingly small concentration in solutions of cupric and ferrous sulphate and the direct precipitation of chalcocite is by no means unlikely. More data on this synthesis are needed, especially some on the synthesis in an alkaline environment.

Covellite, CuS, is found in small amounts in many mining districts of North America but is not abundant in many of the larger deposits. As a rule it is associated with chalcocite, and it forms chiefly as a replacement of iron or zinc sulphides. Weed¹ estimates that covellite has formed 0.5 per cent of the ore mined at Butte. In this region it is secondary and forms in part as an alteration product of chalcocite. It replaces zinc sulphide at Morenci, Ariz.,² in the San Francisco district, Utah,³ at the Poole mine in the foothill copper belt of California,⁴ and elsewhere. At Lake City, Colo.,⁵ according to Irving and Bancroft, small masses of blue sulphide, on being broken into minute cleavage blocks, were found to be sphalerite thinly coated along the numerous cleavage surfaces with covellite films.

In the Last Chance mine of the Cœur d'Alene district, Idaho, lumps of covellite contain minute specks of chalcopyrite, from which the covellite has been formed as an alteration product.⁶ It is abundant in the disseminated copper ores at Bingham, Utah, according to B. S. Butler,⁷ and was noted by Boutwell⁸ coating chalcopyrite in the Northern Light mine. It forms from chalcopyrite and pyrite in the Rambler mine, Encampment, Wyo., and in the Eureka pit at Copper Flat, Nev.⁹ At Ducktown, Tenn., it covers pyrrhotite. According to Lindgren covellite is found coating pyrite in sericitized porphyry at Morenci, Ariz.,¹⁰ and it replaces pyrite also in the Nevada Douglas mine, near Yerington, Nev.

¹ Weed, W. H., *Geology and ore deposits of the Butte district, Montana*: Prof. Paper U. S. Geol. Survey No. 74, 1912, pp. 72, 76.

² Lindgren, Waldemar, *The copper deposits of the Clifton-Morenci district, Arizona*: Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 183.

³ Butler, B. S., oral communication.

⁴ Rogers, A. F., *A new synthesis and new occurrences of covellite*: School of Mines Quart., Columbia Univ., 1911, p. 300.

⁵ Irving, J. D., and Bancroft, Howland, *Geology and ore deposits near Lake City, Colo.*: Bull. U. S. Geol. Survey No. 478, 1911, p. 64.

⁶ Ransome, F. L., and Calkins, F. C., *The geology and ore deposits of the Cœur d'Alene district, Idaho*: Prof. Paper U. S. Geol. Survey No. 62, 1908, p. 92.

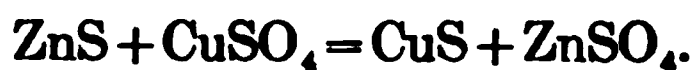
⁷ Oral communication.

⁸ Boutwell, J. M., *Economic geology of the Bingham mining district, Utah*: Prof. Paper U. S. Geol. Survey No. 38, 1905, p. 223.

⁹ Rogers, A. F., *A new synthesis and new occurrences of covellite*: School of Mines Quart., vol. 32, 1911, p. 302.

¹⁰ Lindgren, Waldemar, *op. cit.*, p. 186.

Since the precipitation of cupric sulphide from cupric sulphate solutions involves no change of valence, some very simple equations may be written:



With pyrite the reaction is probably more involved.

Like chalcocite, covellite is formed in a reducing environment, doubtless in the presence of ferrous sulphate, but some ferric salt may be present also. A paragenesis noted by Kemp at Copper Mountain, British Columbia, and described by Catherinet,¹ strongly suggests the presence of ferric ion. The copper minerals, presumably secondary, were formed in the following order: (1) Bornite, (2) covellite and limonite, (3) chalcocite, (4) chalcopyrite and chalcocite. The hydrous iron oxide appears to have formed with covellite between bornite and chalcocite. In view of the fact that limonite forms from ferric rather than from ferrous salt, this association indicates the presence of ferric sulphate. Possibly the iron was deposited from suspension. In this connection the occurrence of considerable finely divided iron oxide suspended in deep waters at Ducktown, Tenn., is suggestive. On the other hand, it is known that changes in acidity bring about reversals in the state of oxidation of some ions in a solution, and the iron oxide may have been precipitated from solution with covellite. The mass of evidence seems to indicate, however, that the precipitation of oxides with copper sulphides is generally subordinate.

Covellite, like chalcocite, is found in ores of the "Red Beds" of the Southwest, where it was deposited as a primary mineral, presumably from cold solutions. Examples of its deposition by ascending thermal waters are exceedingly rare, but at Butte, Mont., it is found at depths as great as 1,600 feet and in associations which, according to Sales,² suggest its deposition by ascending waters. A suite of specimens from the lower levels of the Butte mines, in a collection at the University of Minnesota, shows covellite intergrown with tetrahedrite.

Bornite, Cu_5FeS_4 , is found in associations that indicate its formation under many different geologic conditions. It has not been clearly identified as a pyrogenic constituent of an igneous rock, but it is a primary mineral of a pegmatite at Copper Mountain, British Columbia,³ and it is primary in many contact-metamorphic deposits.

¹ Catherinet, Jules, Copper Mountain, British Columbia: Eng. and Min. Jour., vol. 79, 1905, p. 125.
Kemp, J. F., Secondary enrichment in ore deposits of copper: Econ. Geology, vol. 1, 1906, p. 16.

² Sales, B. H., Discussion of paper by F. L. Ransome, on "Criteria of downward sulphide enrichment": Econ. Geology, vol. 5, 1910, p. 682.

³ Kemp, J. F., Secondary enrichment in ore deposits of copper: Econ. Geology, vol. 1, 1906, p. 17; The rôle of the igneous rocks in the formation of veins: Trans. Am. Inst. Min. Eng., vol. 31, 1902, pp. 182-183.

It occurs in lodes that were formed at great depths and also in some that were formed at moderate depths, and less abundantly in deposits remote from outcrops of igneous rocks.¹ It is deposited on pyrite and other sulphides by cold copper sulphate waters, and in some deposits it is regarded as an important secondary sulphide. As such it is usually much less abundant than chalcocite. According to Sales² it is both primary and secondary at Butte, Mont., where it results from alterations of pyrite, chalcocite, and enargite and is a transition product between pyrite and chalcocite. According to Weed³ it is found mainly above the 1,000-foot level. Sales states that "bornite does not often result from the action of downward-moving surface waters but is generally a product of ascending solutions." Graton⁴ regards it as a primary mineral in the copper deposits of Shasta County, Cal., in some of which it is found as far as 970 feet below the surface. At Bingham, Utah,⁵ bornite is intimately associated with chalcopyrite in the large replacement ore bodies. It is a secondary mineral at Rio Tinto, Spain.⁶

Chalcopyrite, FeCuS_2 , in the greater number of its occurrences is clearly primary, and in many sulphide deposits it is the only important primary copper mineral in the unaltered ore. A list of occurrences of primary chalcopyrite would include nearly all important deposits of copper ore in the United States. It is, however, a "persistent" mineral, and evidence is rapidly multiplying that it is secondary in many deposits. At Bingham, Utah, according to Boutwell,⁷ chalcopyrite is the most important primary copper mineral. It is intimately associated in physical mixtures with pyrite, much of the pyritic ore carrying 3.5 per cent of copper. In the disseminated secondary ores in porphyry a considerable part of the copper is in chalcopyrite. Since it is most abundant in crushed and altered areas, and since it generally occurs along fractures, Boutwell regards it as formed subsequent to the solidification of the porphyry but does not state the nature of the solutions which deposited it. It is a primary constituent of the quartz monzonite at Butte, Mont., and also of the copper ores, but according to Weed⁸ it is not an

¹ Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: Prof. Paper U. S. Geol. Survey No. 68, 1910, pp. 77-78.

² Sales, R. H., Discussion of paper by F. L. Ransome, on "Criteria of downward sulphide enrichment": Econ. Geology, vol. 5, 1910, p. 682.

³ Weed, W. H., Geology and ore deposits of the Butte district, Montana: Prof. Paper U. S. Geol. Survey No. 74, 1912, p. 74.

⁴ Graton, L. C., The occurrence of copper in Shasta County, Cal.: Bull. U. S. Geol. Survey No. 430, 1910, pp. 104-105.

⁵ Boutwell, J. M., Economic geology of the Bingham mining district, Utah: Prof. Paper U. S. Geol. Survey No. 38, 1905, p. 106.

⁶ Finlayson, A. M., The pyritic deposits of Huelva, Spain: Econ. Geology, vol. 5, 1910, p. 419.

⁷ Boutwell, J. M., op. cit., p. 106.

⁸ Weed, W. H., op. cit., p. 75.

important ore mineral at Butte. At Globe it is associated with pyrite in the deeper ores and is abundant in some mines. It occurs with specularite in the Old Dominion, Gibson, and other mines.¹ No secondary occurrence is mentioned by Ransome.² At Bisbee it is in the main but not altogether primary. Some of it is of more recent origin than pyrite. Specimens taken from the periphery of the ore body on the seventh level of the Spray mine, near the inclosing altered and pyritized limestone, show massive chalcopryrite enveloping kernels of pyrite, and veinlets of chalcopryrite traverse the pyritic nuclei. Ransome says:³ "It is necessary to conclude that this particular mass of chalcopryrite was formed after the pyrite and probably in part by alteration or replacement of the latter." According to Kemp,⁴ thin films of later chalcopryrite have been found at Butte, Mont., filling crevices between the tabular crystals of covellite, and it is clearly a secondary mineral at Copper Mountain, near Princeton, British Columbia,⁵ where it is associated with chalcocite and covellite and is probably later than some of the chalcocite of the ore. In Shasta County, Cal.,⁶ it occurs with zinc blende in veinlets cutting the primary ore, and Graton regards it as in part of secondary origin. At Philipsburg, Mont., it occurs sparingly with zinc blende in veinlets which cut the earlier ore. In the veins of Morenci, Ariz.,⁷ chalcopryrite is mainly a primary mineral. In a stope of the Ryerson mine it is associated with chalcocite. Of this occurrence Lindgren says: "Such a connection would suggest its origin as due in this case to secondary sulphide formation by solutions from above, for it is known that chalcopryrite, as well as chalcocite, may form under such conditions." Chalcopryrite is secondary in the rich ore of the Gossan lead, Virginia.⁸ At Ducktown, Tenn.,⁹ and in the Rio Tinto mines, Spain,¹⁰ chalcopryrite enrichment below the chalcocite zone has been a process of considerable economic importance.

Of the chemistry of the precipitation of secondary chalcopryrite very little is known. It has not been formed synthetically by cold sulphate solutions in the laboratory. Since it is a sulphide of both

¹ Ransome, F. L., oral communication.

² Ransome, F. L., *Geology of the Globe copper district, Arizona*: Prof. Paper U. S. Geol. Survey No. 12, 1903, p. 121.

³ Ransome, F. L., *The geology and ore deposits of the Bisbee quadrangle, Arizona*: Prof. Paper U. S. Geol. Survey No. 21, 1904, p. 133.

⁴ Kemp, J. F., *Secondary enrichment in ore deposits of copper*: Econ. Geology, vol. 1, 1906, p. 16.

⁵ Catherinet, Jules, *Copper Mountain, British Columbia*: Eng. and Min. Jour., vol. 79, 1905, pp. 125-126.

⁶ Graton, L. C., *The occurrence of copper in Shasta County, Cal.*: Bull. U. S. Geol. Survey No. 430, 1910, p. 104.

⁷ Lindgren, Waldemar, *The copper deposits of the Clifton-Morenci district, Arizona*: Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 106.

⁸ Weed, W. H., *Copper deposits of the Appalachian States*: Bull. U. S. Geol. Survey No. 455, 1911, pp. 120-121.

⁹ Emmons, W. H., and Laney, F. B., *Preliminary report on the mineral deposits of Ducktown, Tenn.*: Bull. U. S. Geol. Survey No. 470, 1911, p. 151.

¹⁰ Finlayson, A. M., *The pyritic deposits of Huelva, Spain*: Econ. Geology, vol. 5, 1910, pp. 410-420.

copper and iron, and since iron sulphide dissolves in acid, it would be supposed that chalcopyrite would not be precipitated in more than feebly acid solutions, although copper sulphide may be precipitated in solutions more highly acid. In view of these relations it would be supposed that the precipitation of chalcopyrite would be chiefly below the chalcocite zone. Such relations are suggested by the occurrences of these minerals in some districts, especially at Ducktown, Tenn.

Enargite, Cu_3AsS_4 , is a primary mineral of great value at Butte, Mont., is present in considerable amount at Tintic, Utah, and occurs in less abundance at Bingham, Utah, in Gilpin County, Colo., and elsewhere. At Bingham it was found lining druses, showing that it was one of the last minerals deposited, but according to Boutwell¹ there is no conclusive evidence that it was deposited by sulphate waters. The enargite of Butte, according to Emmons and Tower, is primary.² Weed³ observes that some of it was deposited, however, by hot ascending solutions after the earlier chalcopyrite veins had formed. Both Reno Sales⁴ and A. N. Winchell⁵ regard enargite at Butte as mainly primary. It is found in the upper portions of veins above the water level at Butte and at Tintic, but in view of its great insolubility⁶ in acid sulphate waters it is probably residual. Little conclusive paragenetic evidence is available that it is deposited by descending sulphate waters. At Butte it is intergrown with chalcocite, but as stated above some of the chalcocite of the Butte deposits is probably primary.

Famatinite, Cu_3SbS_4 , is not a common ore of copper, and little is known as to its origin. I know of no occurrence that has been described as secondary. In view of the primary origin of enargite, its corresponding arsenic salt, famatinite also is probably of primary origin.

Tetrahedrite, $\text{Cu}_8\text{Sb}_2\text{S}_{11}$, is a comparatively common copper mineral. In most of its occurrences it is of primary origin. Its genesis is discussed on page 124.

Tennantite, $\text{Cu}_3\text{As}_2\text{S}_7$, is the arsenic salt corresponding to tetrahedrite, but it is not so common as tetrahedrite. Its genesis is discussed on page 125.

¹ Boutwell, J. M., Economic geology of the Bingham mining district, Utah: Prof. Paper U. S. Geol. Survey No. 38, 1905, p. 108.

² Weed, W. H., Emmons, S. F., and Tower, G. W., Butte special folio (No. 38), Geol. Atlas U. S., U. S. Geol. Survey, 1897, p. 6.

³ Weed, W. H., Ore deposition and vein enrichment by ascending hot waters: Trans. Am. Inst. Min. Eng., vol. 33, 1903, p. 748.

⁴ Sales, R. H., Discussion of paper by F. L. Ransome, on "Criteria of downward sulphide enrichment": Econ. Geology, vol. 5, 1910, p. 681.

⁵ Winchell, A. N., *idem*, p. 488.

⁶ Buehler, H. A., and Gottschalk, V. H., Oxidation of sulphides: Econ. Geology, vol. 5, 1910, p. 31.

SOME CHEMICAL RELATIONS AND MINERALS OF SILVER.

PRINCIPAL SILVER MINERALS.

The chemical composition of the principal silver minerals is given below:

hypo

Silver.....	Ag.
Cerargyrite.....	AgCl.
Bromyrite.....	AgBr.
Embolite.....	Ag(Cl, Br).
Iodyrite.....	AgI.
Argentite.....	Ag ₂ S.
Pyrargyrite.....	Ag ₃ SbS ₃ or 3Ag ₂ S.Sb ₂ S ₃ .
Proustite.....	Ag ₃ AsS ₃ or 3Ag ₂ S.As ₂ S ₃ .
Stephanite.....	Ag ₅ SbS ₄ or 5Ag ₂ S.Sb ₂ S ₃ .
Polybasite.....	Ag ₉ SbS ₆ or 9Ag ₂ S.Sb ₂ S ₃ .
Pearceite.....	Ag ₉ AsS ₆ or 9Ag ₂ S.As ₂ S ₃ .
Tetrahedrite	4Cu ₂ S.Sb ₂ S ₃ or 4(Cu ₂ Ag ₂)S.Sb ₂ S ₃ .
Tennantite (argentiferous).....	4Cu ₂ S.As ₂ S ₃ or 4(Cu ₂ Ag ₂)S.As ₂ S ₃ .
Tellurides.	

SOLUBILITIES OF SALTS OF SILVER.

The solubilities of several silver salts in water, determined by Kohlrausch,¹ are as follows:

Ag ₂ SO ₄	Ag ₂ CO ₃	AgNO ₃	AgCl	AgBr	AgI
5.5 .02	0.03 .0001	2134 8.6	0.0016 .00001	0.0001 .0000006	0.000003 .00000001

The upper number in each column shows the number of grams of the anhydrous salt held in solution in a liter of water, the lower number shows the molar solubility—the number of mols contained in 1 liter of the saturated solution at 18° C. A more recent determination of the solubility of Ag₂SO₄ is 7.7 grams per liter at 17° C.²

NATURE AND RELATIONS OF THE SILVER MINERALS.

Silver, like copper, is dissolved in dilute sulphuric acid, and the solubility of its sulphide, like that of the sulphides of copper, is increased by the presence of an oxidizing agent. Like copper, it is precipitated in a reducing environment by metallic sulphides or by hydrogen sulphide. Its sulphide is even less soluble than that of copper. Unlike copper, it does not form stable carbonates, sulphates, or oxides in the oxidizing zone. Its chloride is comparatively insoluble, however, whereas the chlorides of copper dissolve more readily

¹ Determined by the conductivity method. See Smith, Alexander, Introduction to inorganic chemistry, rev. ed., New York, 1910, p. 544.
² Euler, Hans, Über Löslichkeitserniedrigung: Zeitschr. phys. Chemie, vol. 49, 1904, p. 314.

and rarely accumulate as ores. Although ferrous sulphate and copper sulphate are compatible even in solutions of high concentration, ferrous sulphate precipitates metallic silver from a dilute solution of its sulphate. As silver is 50 to 100 times as valuable as copper, the natural processes which even slightly enrich silver ores are of great commercial interest.

Silver sulphate, which is only slightly soluble, is formed by the action of concentrated sulphuric acid on silver. Ostwald¹ states that silver sulphate is more soluble in dilute sulphuric acid than in water and that in the reaction an acid salt is probably formed. H. C. Cooke, who recently made a series of experimental studies in the solution and precipitation of silver compounds, informs me that silver sulphide is only slightly soluble in very dilute sulphuric acid, but that if a little ferric sulphate is added to the solution the solubility of the sulphide is considerably increased. He found also that a little ferric sulphate is almost as effective as a considerable amount and believes that the function of ferric sulphate is to oxidize any hydrogen sulphide that is formed, removing it from the system, in which it would suppress further solution of silver sulphide. According to Vogt² ferric sulphate will itself attack metallic silver. Like gold chloride, silver sulphate is easily reduced by many minerals depositing the native metal.

The order of the solubility of the chloride, the bromide, and the iodide of silver are expressed by the order in which they are here named. All of them are very sparingly soluble in water; consequently the halogens will precipitate silver from sulphate solutions and the halides may remain in the upper portions of deposits, giving a considerable enrichment at or near the surface. "In consequence of the progressive insolubility, a cold solution of a bromide will slowly convert the precipitate of silver chloride into bromide, and a soluble iodide will similarly transform the bromide or the chloride into iodide."³ If the three halogens were equally abundant in mine waters, the bromide and iodide of silver would probably predominate in the silver deposits, but chlorine only is abundant. Consequently cerargyrite, AgCl , is much more common than embolite, $\text{Ag}(\text{Cl}, \text{Br})$; bromyrite, AgBr ; iodobromite, $\text{Ag}(\text{Cl}, \text{Br}, \text{I})$; and iodyrite, AgI .

If, in a solution containing the three halogens, chlorides are vastly in excess, silver chloride will be precipitated first, even if bromides and iodides are present, for in mixed solution the least soluble salts are not precipitated first if a more soluble salt is present in sufficiently greater concentration.

¹ Ostwald, Wilhelm, *The principles of inorganic chemistry* (trans. by Alex. Findlay), London, 1904, p. 670.

² Vogt, J. H. L., *Problems in the geology of ore deposits*, in Pošepný, Franz, *The genesis of ore deposits*, 1902, p. 677.

³ Smith, Alexander, *Introduction to inorganic chemistry*, rev. ed., New York, 1910, p. 620.

The relations of the halides of silver at Tonopah, Nev., should be mentioned in this connection. According to Burgess¹ the silver halides at some places occupy fairly well marked horizons in the altered veins. The chloride, cerargyrite, occupies the upper zone embolite the middle zone, and iodyrite the lower zone. The zones are usually not distinct, and in places two of the minerals are found together. Of these relations Burgess says:²

The order of crystallization was chloride, bromochloride, iodide, which is contrary to what would be expected from their respective solubilities, since iodide is the least soluble and would be expected to precipitate first. The reason for this reversal may be involved in the complicated set of conditions under which the reactions occurred and the numerous other minerals present. The most obvious explanation seems to be that the chloride was precipitated first because of the great excess of alkaline chlorides in the solution, and that as the chlorine became reduced in quantity it was partly replaced by bromine, and that the iodide was formed only after the concentration of the other halogens was considerably reduced.

Notwithstanding the low solubilities of the silver halides, it seldom happens that all the silver dissolved in the upper parts of an argenterous deposit is fixed as halides. The formation of the chloride near the surface does not entirely inhibit the downward migration of silver. The secondary silver sulphides are numerous and in some veins abundant. Among the reasons for the fairly extensive downward migration of silver, even where chlorides are formed, the following may be mentioned:

1. Chlorides are present in the natural waters in some deposits in amounts insufficient to precipitate as chloride all the silver that goes into solution as sulphate.
2. Silver chloride is itself slightly soluble in water.
3. Silver chloride and other halides of silver are soluble in an excess of alkali chlorides.

From this it follows that if a silver solution in the upper part of a deposit contains a certain small amount of alkali chlorides some of the silver will be fixed as chloride; but if it contains sufficient alkali chloride horn silver will be dissolved and will migrate downward with other metals. That some silver is held in solutions containing both sulphates and chlorides is shown by an analysis of mine water reported by Reid.³

Silver is readily precipitated as argentite below the zone of oxidation on account of the low solubility of the sulphide— 0.552×10^{-6} mole per liter.⁴ It stands near the end of the Schuermann series, being preceded only by mercury, and accordingly it should replace most

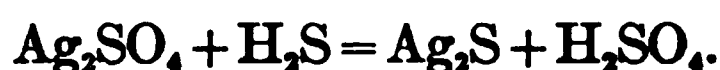
¹ Burgess, J. A., The halogen salts of silver and associated minerals at Tonopah, Nev.: *Econ. Geology*, vol. 6, 1911, p. 13.

² *Idem*, p. 15.

³ Reid, J. A., The structure and genesis of the Comstock lode: *Bull. Dept. Geology Univ. California*, vol. 4, 1906, pp. 189-190.

⁴ Weigel, Oskar, Die Löslichkeit von Schwermetallsulfiden in reinem Wasser: *Zeitschr. phys. Chem.*, vol. 53, 1907, p. 294.

other metals in sulphide combinations. Ferrous sulphate formed by the reaction of dilute acid and ferric sulphate waters on the several sulphides will precipitate metallic silver from sulphate solutions. With silver sulphate (Ag_2SO_4) hydrogen sulphide, which, under some conditions at least, is generated by acid reacting upon zinc blende, galena, or other sulphides, gives argentite, which is one of the most important silver minerals in ores. The reaction is—



If the reaction is with galena, or if lead sulphide is precipitated simultaneously with argentite, argentiferous galena may be formed. If arsenic and antimony are present in solution, the complex sulphosalts of these metals may be formed. Of these pyrargyrite is probably the most abundant. Very little is known of the manner of formation of the arsenic and antimony compounds. That both are dissolved in underground water is indicated by the small amounts of arsenic and antimony in gossans and oxidized zones of deposits which contain more of these metals in depth. Although several samples of mine waters show traces of arsenic and antimony, few waters contain appreciable quantities of these elements. The synthesis of the complex compounds they form is difficult under the conditions that are assumed to exist where sulphide enrichment takes place. It is generally supposed that most of them may be either primary or secondary. The data now available indicate that pyrargyrite and proustite are nearly everywhere secondary minerals; that stephanite, polybasite, and pearceite are secondary in most of their occurrences; that tetrahedrite and tennantite, which frequently contain silver as well as copper, are in general primary. The two minerals last named are found at some places in cracks that cut the primary ore, but it is not clear that their occurrence is related to the present topographic surface.

In the subjoined table the more important antimony sulphosalts of silver are put in the first column, the arsenic sulphosalts in the second. Tetrahedrite and tennantite are included, for they are frequently argentiferous.

Rather common.	Rare.
Pyrargyrite= $3\text{Ag}_2\text{S}.\text{Sb}_2\text{S}_3$.	Proustite= $3\text{Ag}_2\text{S}.\text{As}_2\text{S}_3$.
Tetrahedrite= $4\text{Cu}_2\text{S}.\text{Sb}_2\text{S}_3$.	Tennantite= $4\text{Cu}_2\text{S}.\text{As}_2\text{S}_3$.
Stephanite= $5\text{Ag}_2\text{S}.\text{Sb}_2\text{S}_3$.	
Polybasite= $9\text{Ag}_2\text{S}.\text{Sb}_2\text{S}_3$.	Pearceite= $9\text{Ag}_2\text{S}.\text{As}_2\text{S}_3$.

The minerals in the first column are, as a rule, much more abundant and they are of commoner occurrence than the corresponding minerals in the second column. Proustite is probably less common and less abundant than pyrargyrite, tennantite less common and less abundant than tetrahedrite. Polybasite is not an uncommon mineral, but pearceite has been identified at only a few places.

If the antimony sulphosalts, where secondary, have been deposited mainly as results of reactions of silver-bearing sulphate waters on stibnite, it would appear that arsenic minerals are less common than the antimony minerals or else that they are less readily replaced under the conditions that exist in veins.

Although there is no invariable rule respecting the relations of the silver chloride, the native metal, the sulphide, and the arsenic and antimony sulphosalts in deposits containing all these minerals, yet in some such deposits some of these minerals have fairly well defined horizons. The chloride is most abundantly developed above the argentite ore; the antimony and arsenic sulphosalts are found with and below the argentite. The native metal is found with the chloride, and, overlapping the zone of chloride ores, it extends downward with argentite. In the Granite-Bimetallic mine, at Philipsburg, Mont., the deeper secondary ores contain very little argentite or native metals, the richer minerals being almost exclusively the dark and the light ruby silver. At Georgetown, Colo., according to Spurr, Garrey, and Ball, argentite predominates in the upper part of the secondary sulphide zones, and the secondary arsenic and antimony sulphosilver minerals are more important below the argentite zone.

OCCURRENCE OF THE SILVER MINERALS.

Native silver is a primary mineral in some deposits, as in the zeolitic copper ores of Lake Superior, but in sulphide deposits it is generally or invariably secondary. In some districts it is among the most important ore minerals. It commonly occurs as thin flakes or as sheets plastered on the older minerals or as veinlets filling cracks in the ore, and presumably has been formed at many places through the reduction of silver sulphides or other silver-bearing minerals. In the Aspen mining district, Colo., native silver coats crystals of barite and is undoubtedly of relatively late deposition. Wire silver piercing barite is found 900 feet below the surface.¹ According to Spurr,² silver replaces organic remains in the Aspen district and is found probably 600 feet below the level of ground water. There, he says, in consequence of reduction by carbonaceous matter in the "Weber shales" it has formed instead of the complex salts of silver which generally constitute the richer ores in this province. By processes of reduction native silver forms as an alteration product of many minerals, such as argentite, pyrargyrite, proustite, polybasite, and stephanite. At many places it is pseudomorphous after these. Vogt³ says that the native silver of Königsberg, which is

¹ Lindgren, Waldemar, oral communication.

² Spurr, J. E., *Geology of the Aspen mining district, Colorado*: Mon. U. S. Geol. Survey, vol. 31, 1898, p. 233; *Ore deposition at Aspen, Colo.*: Econ. Geology, vol. 4, 1909, p. 315.

³ Vogt, J. H. L., *Ueber die Bildung des gediegenen Silbers, besonders des Königsberger Silbers, durch Secundärprocessen aus Silberglanz und anderen Silbererzen*: Zeitschr. prakt. Geologie, vol. 7, 1899, pp. 112-123, 177-181.

noted for its large and beautiful specimens, is formed by the reduction of argentite. Weed¹ states that secondary silver ore at Butte is probably first precipitated as argentite, which alters to the native metal. In the Comstock lode native silver is rare but has been noted. At Georgetown, Colo.,² polybasite is covered with small specks of native silver, which is probably secondary to the polybasite. At Tonopah, Nev., native silver is not abundant but has been observed coating cracks in the primary ore and is entirely secondary.³ In the Cœur d'Alene district, Idaho, wire silver is associated with cerusite and limonite in the upper parts of several of the lead-silver veins.⁴ It was an important ore in silver veins and in oxidized portions of copper veins at Butte and in several other districts of Montana. It was found at Creede, Colo., 1,200 feet below the surface. In this district chalcedony and native silver form rich ore. The native silver in deposits of Cobalt, Ontario, is considered secondary.

Ferrous sulphate precipitates silver from sulphate solutions, according to the following reaction:⁵



This reaction doubtless accounts for some well-authenticated occurrences of native silver veinlets below the water level, but many other natural precipitants are known.⁶

Cerargyrite, horn silver, AgCl , is probably unknown as a primary constituent of ores deposited by ascending hot waters but is frequently developed by weathering, alteration, or enrichment at or near the outcrops of silver-bearing sulphide lodes. A list of its occurrences would include nearly all sulphide deposits in which silver is an important metal. In arid undrained areas it is an important ore mineral, so important that the term "chloriding" is generally used in such regions for pocket hunting near the surface. At many places even where the primary sulphide ores are not profitable the superficial chloride ores may be very rich. The chloride ores generally pass into the sulphides below, and the bottom of the zone of ore carrying horn silver is generally above the bottom of the zone of secondary silver sulphides. Cerargyrite is not everywhere confined to the shallow surface zone, however. In the Comstock lode, where it is not particularly abundant, it was noted, according to Clarence King, at a depth of 900 feet below the surface. Cerargyrite

¹ Weed, W. H., *Geology and ore deposits of the Butte district, Montana*: Prof. Paper U. S. Geol. Survey No. 74, 1912, p. 102.

² Spurr, J. E., and Garrey, G. H., *Preliminary report on the ore deposits of the Georgetown mining district, Colorado*: Bull. U. S. Geol. Survey No. 260, 1905, p. 119.

³ Spurr, J. E., *Geology of the Tonopah mining district, Nevada*: Prof. Paper U. S. Geol. Survey No. 42, 1905, p. 95.

⁴ Ransome, F. L., and Calkins, F. C., *The geology and ore deposits of the Cœur d'Alene district, Idaho*: Prof. Paper U. S. Geol. Survey No. 62, 1908, p. 90.

⁵ Penrose, R. A. F., jr., *The superficial alteration of ore deposits*: Jour. Geology, vol. 2, 1894, p. 314.

⁶ For the relations of native silver and copper minerals, see this paper, p. 97.

forms where waters carrying silver sulphates encounter waters bearing chlorides. Silver chloride is only slightly soluble in ordinary ground water and is therefore fairly stable under surface conditions.

Many deposits of cerargyrite ores contain large amounts of manganese oxide. In some of these native silver is present only in small quantity. The presence of manganese oxide delays the generation of ferrous sulphate, which, as already stated, precipitates native silver from ferric sulphate solution. With manganese dioxide in the presence of abundant chlorides horn silver would be precipitated rather than the native metal. Examples of horn-silver ores associated with manganese oxides include the famous deposits of Lake Valley,¹ near Silver City, N. Mex., the deposits of the Exposed Treasure mine,² near Mohave, Cal., and some silver deposits at Neihart, Mont.,³ and at Leadville, Colo.⁴ Other deposits, however, containing appreciable though lower proportions of manganese, contain considerable native silver with subordinate chloride; a conspicuous example is the Amethyst vein of Creede, Colo.

Embolite and other halides.—Embolite, $\text{Ag}(\text{Cl}, \text{Br})$; bromyrite, AgBr ; iodobromite, $\text{Ag}(\text{Cl}, \text{Br}, \text{I})$; and iodyrite, AgI , are not common minerals, for they contain bromine and iodine, which are rare in mineral solutions. None of them are known to have been formed in hot ascending solutions. They are in the main even less soluble in water than cerargyrite and are therefore comparatively stable when once they are formed. The mutual relations of the silver halides at Tonopah, Nev., have already been reviewed (p. 116).

Argentite, Ag_2S , is one of the commonest and most important secondary silver minerals, but it occurs also as a primary mineral. It fills postmineral cracks in the secondary zones at Georgetown, Colo., Neihart and Philipsburg, Mont., and many other places. Great bonanzas of argentite were found in upper levels on the Comstock lode. In this lode it has been identified as far as 3,000 feet below the surface but not certainly as a secondary mineral. At Tonopah, Nev.,⁵ some occurrences of argentite are primary, but in places it coats crevices that cut the primary ore and is evidently secondary also. Some of the ores show argentite fringing cerargyrite, as if secondary to it. It is probably primary in part at Butte,

¹ Clark, Ellis, The silver mines of Lake Valley, New Mexico: Trans. Am. Inst. Min. Eng., vol. 24, 1895, p. 148. Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: Prof. Paper U. S. Geol. Survey No. 68, 1910, pp. 66, 279.

² De Kalb, Courtenay, Geology of the Exposed Treasure lode, Mojave, Cal.: Trans. Am. Inst. Min. Eng., vol. 38, 1908, p. 319.

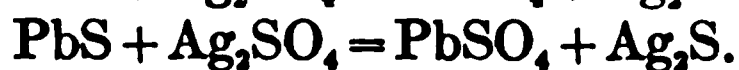
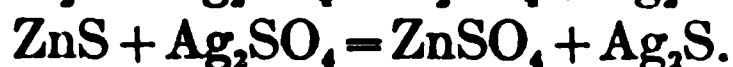
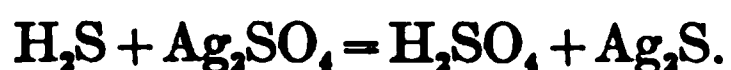
³ Weed, W. H., Geology of the Little Belt Mountains, Montana, with notes on the mineral deposits of the Neihart, Barker, Yogo, and other districts, accompanied by a report on the petrography of the igneous rocks of the district by L. V. Pirsson: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, p. 407.

⁴ Emmons, S. F., Geology and mining industry of Leadville, Colo.: Mon. U. S. Geol. Survey, vol. 12, 1886, p. 562.

⁵ Spurr, J. E., Geology of the Tonopah mining district, Nevada: Prof. Paper U. S. Geol. Survey No. 42, 1905, pp. 92, 94.

Mont., and at Tintic, Utah. Argentite is pseudomorphous after ruby silver (and vice versa) at Joachimsthal, Bohemia.

Silver sulphide is the least soluble sulphide of the commoner metals, except mercury and bismuth, and in reactions involving double decomposition it would be precipitated from argentiferous solutions before all except these sulphides. A search for pseudomorphs after copper sulphide, sphalerite, and pyrite has shown surprisingly few clearly defined examples, although it probably does replace these sulphides metasomatically. If sulphuric acid should in its descent encounter a soluble sulphide like zinc blende, hydrogen sulphide and zinc sulphate might be formed. The hydrogen sulphide would precipitate silver sulphide from a solution containing Ag_2SO_4 . Argentite could be precipitated in any of the following reactions:



The precipitation of argentite from silver sulphate solution does not necessitate a change in valence like that which takes place when chalcocite is formed.

Pyrargyrite, dark ruby silver, $3\text{Ag}_2\text{S} \cdot \text{Sb}_2\text{S}_3$, is probably the most important secondary silver mineral in a large number of silver mines in the United States. So far as known, it is confined to epigenetic deposits, and it is particularly conspicuous in many deposits of early and middle Tertiary age in the American Cordillera. It is not known as a primary mineral of contact-metamorphic and nearly related deposits. In the Granite-Bimetallic mine, at Philipsburg, Mont., pyrargyrite is perhaps the most important mineral. It occurs as small specks intimately intergrown with quartz and stibnite and may possibly be primary, but it is very much more abundant as a secondary mineral in this mine. Most of it lines vugs or occurs in small veinlets that cut across the banding of the primary ore, in which stibnite is abundant. At Tonopah, Nev., pyrargyrite coats crevices that cut the primary ore and is evidently secondary.¹

Little is known of the synthesis of pyrargyrite under conditions of sulphide enrichment. The assumption that it forms under such conditions rests on paragenetic evidence and the fact that it frequently disappears with increase in depth. Pyrargyrite is an important ore mineral at Georgetown, Lake City, Ouray, and Telluride, Colo.; at the Comstock lode, Austin, Tuscarora, and other districts of Nevada; and at Neihart, Butte, and other places in Montana. At all these places it is probably, in part, at least, of secondary origin.

¹ Spurr, J. E., *Geology of the Tonopah mining district, Nevada*: Prof. Paper U. S. Geol. Survey No. 42, 1906, p. 94.

Pyrargyrite is an important constituent of the ore of the famous silver mines of Zacatecas, Guanajuato, and Pachuca, Mexico. Mineralogically the ores of these deposits are nearly related to those of the Comstock lode and Tonopah, Nev.

On the horizon of pyrargyrite at Lake City, Colo., the following, from Irving and Bancroft,¹ is a particularly clear statement:

Ruby silver occurred, so far as could be learned, in all of the mines at the plane of demarcation between sulphides and oxides and, in generally decreasing quantity, to several hundred feet below this level. Along cracks and fissures it occurred in isolated masses to great depths—for instance, at 1,200 feet in the Golden Fleece and at 1,300 feet in the Ilma. These deep occurrences are, however, uncommon and merely indicate the presence of some easy line of access for downward-moving solutions.

Ruby silver has probably resulted from the solutions of silver and antimony obtained by the decomposition of the tetrahedrite and possibly to some extent also from the argentiferous galena. The chemistry of both the solution and reprecipitation of the antimonial and arsenical sulphur compounds has not yet been worked out in sufficient detail to permit a statement of the probable steps of the process, but the geological facts show that it has occurred. The proofs of the secondary character of the ruby silver are:

1. Its restriction in quantity to the upper levels of the mines.
2. Its invariable occurrence as the latest deposited mineral in the veins, either in cracks or crevices in shattered primary ore or as crystals in cavities.
3. Its occurrence only in isolated bunches in deeper workings, where its origin is probably due to the presence of water channels that permit the downward percolation of water from above.
4. Its complete absence from the great mass of deep-seated ore.

It is clearly secondary in all of a large number of specimens of silver ores from the Southwest.

In some mines ruby silver is found at very considerable depths, however, possibly below the zone of secondary alteration. At Przibram, for example, it is said to be found 3,500 feet below the surface.

Proustite, light ruby silver, $3\text{Ag}_2\text{S} \cdot \text{As}_2\text{S}_3$, is similar to pyrargyrite in its occurrence and is commonly regarded as a secondary mineral. Whether it is ever primary is a moot question. Proustite is a secondary mineral at Lake City, Ouray, Silverton, Telluride, and Rico, Colo.,² at Philipsburg, Mont., at Austin, Nev., in the Cœur d'Alene district, Idaho,³ and in several other districts. It has been noted on the Comstock lode but is not abundant there.

Discussing the genesis of argentite, proustite, pyrargyrite, stephanite, and polybasite, Ransome⁴ says:

It is quite possible that further study of ore deposits may result in showing that some of these minerals, especially proustite, are fully as characteristic of downward enrichment as is chalcocite.

¹ Irving, J. D., and Bancroft, Howland, *Geology and ore deposits near Lake City, Colo.*: Bull. U. S. Geol. Survey No. 478, 1911, p. 63.

² Idem, p. 35.

³ Ransome, F. L., and Calkins, F. C., *The geology and ore deposits of the Cœur d'Alene district, Idaho*: Prof. Paper U. S. Geol. Survey No. 62, p. 93.

⁴ Ransome, F. L., *Criteria of downward sulphide enrichment*: Econ. Geology, vol. 5, 1910, p. 211.

Sommerlad¹ prepared proustite by heating silver chloride and arsenic trisulphide, and many other syntheses are known.² I have no record of the formation of proustite in cold sulphate waters.

Stephanite, brittle silver, $5\text{Ag}_2\text{S.Sb}_2\text{S}_3$, is an important mineral on the Comstock lode, at Tuscarora and Tonopah, Nev., at Georgetown, Aspen, and Rico, Colo., and in many other silver districts. It generally accompanies ruby silver and polybasite, and in some districts it occurs, like them, in cracks cutting the primary ore. On the Comstock lode, according to King,³ broken fragments of quartz themselves containing ore have been recemented by sheets of stephanite. In general its occurrences in the United States are not clearly described, and its genesis is more or less uncertain.

Polybasite, $9\text{Ag}_2\text{S.Sb}_2\text{S}_3$, is commonly a secondary mineral. It occurs at Georgetown, Colo., in cracks cutting the primary ore,⁴ and in the main is related to the present surface. At Neihart, Mont.,⁵ it occurs in postmineral fractures and in vugs and incrusts primary sulphides. It occurs with barite in the Mollie Gibson mine at Aspen, Colo., where it alters to native silver.⁶ It is probably secondary in the Comstock lode, Nevada, and in several districts in San Juan, Colo. At Tonopah, Nev.,⁷ polybasite is found as deep as 500 feet below the surface in fractures that cut older sulphides, but according to Spurr it is not certain that it was deposited by descending solutions. In many other districts it is regarded as a secondary mineral, for it is not abundant in the deeper levels.

Although polybasite has been formed synthetically no record of its synthesis from cold sulphate waters is available. H. C. Cooke⁸ treated powdered stibnite with cold dilute silver sulphate solution and obtained a rich antimony-silver ore but did not identify the material as polybasite.

Pearceite, $9\text{Ag}_2\text{S.As}_2\text{S}_3$, is less common than the corresponding antimony salt, polybasite. It is generally assumed to be secondary. According to Weed,⁹ it constitutes much of the rich silver ore of

¹ Sommerlad, Hermann, Über einige Versuche zur Herstellung von Sulfantimoniten und Sulfarseniten des Silbers auf trockenem Wege: Zeitschr. anorg. Chemie, vol. 15, 1897, p. 177; Über Versuche zur Darstellung von Sulfantimoniten und Sulfarseniten des Silbers, Kupfers und Bleis auf trockenem Wege: Idem, vol. 18, 1898, pp. 420-447.

² Clarke, F. W., The data of geochemistry; 2d ed.: Bull. U. S. Geol. Survey No. 491, 1911, p. 624.

³ King, Clarence, The Comstock lode: U. S. Geol. Expl. 40th Par., vol. 3, 1870, p. 81.

⁴ Spurr, J. E., and Garrey, G. H., Economic geology of the Georgetown quadrangle (together with the Empire district), Colo., with general geology by S. H. Ball: Prof. Paper U. S. Geol. Survey No. 63, 1908, p. 261.

⁵ Weed, W. H., Geology of the Little Belt Mountains, Mont., with notes on the mineral deposits of the Neihart, Barker, Yogo, and other districts, accompanied by a report on the petrography of the igneous rocks of the district by L. V. Pirsson: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, p. 407.

⁶ Spurr, J. E., Geology of the Aspen mining district, Colorado, with atlas: Mon. U. S. Geol. Survey, vol. 31, 1898, pp. 224-225.

⁷ Spurr, J. E., Geology of the Tonopah mining district, Nevada: Prof. Paper U. S. Geol. Survey No. 42, 1905, p. 95.

⁸ Unpublished data.

⁹ Weed, W. H., The enrichment of gold and silver veins, in Poëpny, Franz, The genesis of ore deposits, 1902, p. 494.

Neihart, Mont. Pearceite, intimately associated with galena, has been identified¹ from the Mollie Gibson mine, Aspen, Colo. In the Drumlummon mine, Marysville, Mont., according to Penfield,² it lines a vug and is intimately associated with chalcopyrite, calcite, and quartz.

Tetrahedrite, gray copper, $4\text{Cu}_2\text{S.Sb}_2\text{S}_3$, is rather widely distributed but is of subordinate importance as a source of copper. The argenterous variety, freibergite, is an important source of silver in many deposits. In the San Juan region, Colo., tetrahedrite is abundant in many deposits and is regarded as a primary constituent in this region.³ It is primary at Butte, but its corresponding arsenic compound, tennantite, is said to be secondary.⁴ In the Leonard mine some tetrahedrite is later than enargite.⁵ At Ouray and Lake City, Colo., according to Irving and Bancroft,⁶ it was deposited by ascending hot waters, but mainly in the upper parts of the lodes, which at Lake City have a vertical range of over 5,000 feet. The corresponding arsenic compound, tennantite, has not been recognized. Tetrahedrite appears to be primary in Clear Creek County, Colo.⁷ At Cripple Creek, Colo., it is primary and persists to depths of 2,000 feet below the surface.⁸ It is found also at Nevada City⁹ and, intergrown with electrum, at Ophir,¹⁰ Cal. At Elkhorn, Mont.,¹¹ it is probably the parent sulphide of rich altered silver ores.

At Bingham, Utah, according to Boutwell,¹² tetrahedrite is secondary. Crystals of pyrite are coated by chalcopyrite and the latter by tetrahedrite. In the Centennial mine,¹³ in the Empire district, Colorado, tetrahedrite forms in cracks of chalcopyrite in auriferous lodes and is said to be derived from it. Tetrahedrite is said to be second-

¹ Penfield, S. L., On pearceite, a sulpharsenite of silver, and on the crystallization of polybasite: Proc. Colorado Sci. Soc., vol. 5, 1896, p. 211.

² Idem, pp. 217-218.

³ Ransome, F. L., A report on the economic geology of the Silverton quadrangle, Colorado: Bull. U. S. Geol. Survey No. 182, 1901, p. 78; Criteria of downward sulphide enrichment: Econ. Geology, vol. 5, 1910, p. 212.

⁴ Weed, W. H., Emmons, S. F., and Tower, G. W., Butte special folio (No. 38), Geol. Atlas U. S., U. S. Geol. Survey, 1897, p. 6.

⁵ Weed, W. H., Geology and ore deposits of the Butte district, Montana: Prof. Paper U. S. Geol. Survey No. 74, 1912, p. 78.

⁶ Irving, J. D., and Bancroft, Howland, Geology and ore deposits near Lake City, Colo.: Bull. U. S. Geol. Survey No. 478, 1911, pp. 34, 52.

⁷ Kemp, J. F., Secondary enrichment in ore deposits of copper: Econ. Geology, vol. 1, 1906, p. 22.

⁸ Lindgren, Waldemar, and Ransome, F. L., Geology and gold deposits of the Cripple Creek district, Colorado: Prof. Paper U. S. Geol. Survey No. 54, 1906, pp. 121-122.

⁹ Lindgren, Waldemar, The gold-quartz veins of Nevada City and Grass Valley districts, California: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 119.

¹⁰ Lindgren, Waldemar, The gold-silver veins of Ophir, Cal.: Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, p. 273.

¹¹ Weed, W. H., Geology and ore deposits of the Elkhorn mining district, Jefferson County, Mont.: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, p. 450.

¹² Boutwell, J. M., Economic geology of the Bingham mining district, Utah: Prof. Paper U. S. Geol. Survey No. 38, 1905, pp. 107, 220, 222-223.

¹³ Spurr, J. E., and Garrey, G. H., Economic geology of the Georgetown quadrangle (together with the Empire district), Colorado, with general geology by S. H. Ball: Prof. Paper U. S. Geol. Survey No. 63, 1908, p. 148.

Rio Tinto, Spain.¹ The interesting occurrences of primary tetrahedrite veinlets which cut older sulphides in the Mina Mexico vein, Sonora,² are mentioned on page 46.

Tetrahedrite has not been formed synthetically under conditions that prevail in the secondary sulphide zone. The formula of the argentiferous variety, freibergite, has been written as a combination of chalcocite, argentite, and stibnite— $4(\text{Cu}_2\text{S}.\text{Ag}_2\text{S})\text{Sb}_2\text{S}_3$ —but since these minerals have dark streaks and freibergite has a reddish-brown streak, this interpretation of the formula is open to question. Possibly the ruby-silver molecule is present.

Tennantite, $4\text{Cu}_2\text{S}.\text{As}_2\text{S}_3$, is regarded as having the same range of occurrence as the corresponding antimony sulphide, tetrahedrite. It is not so common, however, and comparatively few detailed descriptions of its occurrence as a secondary mineral are available. It is said to be secondary at Butte, Mont.,³ where, according to Emmons and Tower, it seems to result from the decomposition of enargite, with which it is always associated.

Other silver minerals.—Several other silver minerals, all comparatively rare species, have been regarded as secondary. Among these are stromeyerite,⁴ AgCuS ; dyscrasite,⁵ $\text{Ag}_3\text{Sb}(\text{?})$; and possibly stetefeldtite.⁶ Of these, stromeyerite corresponds in composition to argentiferous chalcocite. In the Yankee Girl mine, near Silverton, Colo. it is associated with chalcocite and bornite. Since secondary sulphides of silver and copper are precipitated together, it would be supposed that stromeyerite would develop in many deposits. The silver compound in argentiferous chalcocite has not yet been identified, however.

SOME CHEMICAL RELATIONS AND MINERALS OF GOLD.

SOLUBILITY OF GOLD.

Although gold belongs to the same chemical family as copper and silver it differs in many respects from both these metals. It forms no insoluble compound in the oxidized zone and its sulphide is not precipitated by mineral waters. Unlike copper and silver it is insoluble in sulphuric acid. Wurtz⁷ stated, in 1858, that ferric sulphate dissolves gold, and his statement has frequently been quoted

¹ Finlayson, A. M., The pyritic deposits of Huelva, Spain: *Econ. Geology*, vol. 5, 1910, p. 411.

² Hynes, D. P., Notes on the geology of the Mina Mexico vein: *Econ. Geology*, vol. 7, 1912, pp. 285–286.

³ Weed, W. H., Emmons, S. F., and Tower, G. W., Butte special folio (No. 38), *Geol. Atlas U. S.*, U. S. Geol. Survey, 1897, p. 6.

⁴ Emmons, S. F., The secondary enrichment of ore deposits: *Trans. Am. Inst. Min. Eng.*, vol. 30, 1901, p. 196.

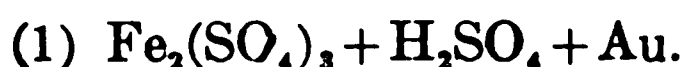
⁵ Smith, George, The ore deposits of the Australian Broken Hill Consols mine, Broken Hill, New South Wales: *Trans. Am. Inst. Min. Eng.*, vol. 26, 1897, pp. 69–78.

⁶ Spurr, J. E., Ore deposits of the Silver Peak quadrangle, Nevada: *Prof. Paper U. S. Geol. Survey No. 55*, 1906, p. 120.

⁷ Wurtz, Henry, Contributions to analytical chemistry: *Am. Jour. Sci.*, 2d ser., vol. 26, 1858, p. 51.

in discussions of the processes of enrichment of gold deposits. It is, indeed, a common statement that ferric sulphate is the principal agent in the enrichment of gold deposits. Stokes¹ showed, however, that ferric sulphate will not dissolve gold, even at 200° C., except in the presence of a chloride, and its insolubility in ferric chloride and in ferric sulphate at ordinary temperatures has been verified by A. D. Brokaw.² W. J. McCaughey³ found that gold is dissolved in a concentrated solution of hydrochloric acid and ferric sulphate and also in a concentrated solution of hydrochloric acid and cupric chloride, both experiments being carried on at temperatures from 38° to 43° C. Pearce,⁴ Don,⁵ and Rickard⁶ performed experiments in which gold was dissolved in the presence of a chloride and manganese dioxide. Hydrochloric acid forms in the presence of sodium chloride and sulphuric acid, and in the presence of an oxidizing agent the hydrogen ion is removed to form water, leaving the chlorine in the so-called "nascent state." In this state it is in the uncombined or atomic condition and its attack is more vigorous. It is known that several oxides will release "nascent chlorine" at low temperatures if the solutions are sufficiently concentrated, but in moderately dilute solutions manganese oxides are probably the only common ones that are appreciably effective. Ferric chloride, ferric sulphate, and cupric salts are not more than a fraction of 1 per cent as effective as manganese salts and doubtless this fraction is exceedingly small.⁷

A number of experiments on the solubility of gold in cold dilute solutions were made at the request of the writer by Mr. A. D. Brokaw.⁸ The nature of these experiments is shown by the following statements, in which *a* and *b* represent duplicate tests:



(a) No weighable loss. (34 days.)

(b) No weighable loss.



(a) No weighable loss. (34 days.)

(b) 0.00017 gram loss.⁹

¹ Stokes, H. N., Experiments on the solution, transportation, and deposition of copper, silver, and gold: *Econ. Geology*, vol. 1, 1906, p. 650.

² Brokaw, A. D., The solution of gold in the surface alterations of ore bodies: *Jour. Geology*, vol. 18, 1910, p. 322.

³ McCaughey, W. J., The solvent effect of ferric and cupric salt solutions upon gold: *Jour. Am. Chem. Soc.*, vol. 31, 1909, p. 1263.

⁴ Pearce, Richard, Discussion of paper by T. A. Rickard, on "The origin of the gold-bearing quartz of the Bendigo Reefs, Australia": *Trans. Am. Inst. Min. Eng.*, vol. 22, 1894, p. 739.

⁵ Don, J. R., The genesis of certain auriferous lodes: *Trans. Am. Inst. Min. Eng.*, vol. 27, 1898, p. 599.

⁶ Rickard, T. A., The Enterprise mine, Rico, Colo.: *Trans. Am. Inst. Min. Eng.*, vol. 26, 1897, pp. 978-979.

⁷ Emmons, W. H., The agency of manganese in the superficial alteration and secondary enrichment of gold deposits in the United States: *Bull. Am. Inst. Min. Eng.*, 1910, pp. 789-791.

⁸ Brokaw, A. D., *op. cit.*, pp. 321-326.

⁹ This duplicate was found to contain a trace of Cl, which probably accounts for the loss.



(a) No weighable loss. (34 days.)

(b) No weighable loss.



(a) 0.01640 gram loss. Area of plate, 383 square millimeters. (34 days.)

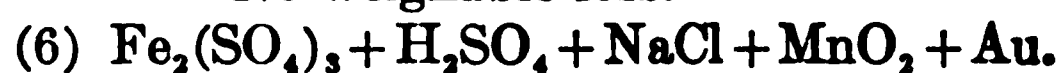
(b) 0.01502 gram loss. Area of plate, 348 square millimeters.

In each experiment the volume of the solution was 50 cubic centimeters. The solution was one-tenth normal with respect to ferric salt and to acid. In the second and fourth experiments 1 gram of powdered manganese dioxide was also added. The gold, assaying 0.999 fine, was rolled to a thickness of about 0.002 inch, cut into pieces of about 350 square millimeters area, and one piece, weighing about 0.15 gram, was used in each duplicate.

To approximate natural waters more closely, a solution was made one-tenth normal as to ferric sulphate and sulphuric acid and one-twenty-fifth normal as to sodium chloride. Then 1 gram of powdered manganese dioxide was added to 50 cubic centimeters of the solution, and the experiment was repeated. The time was 14 days.



No weighable loss.



Loss of gold, 0.00505 gram.

The loss is comparable to that found in experiment 4, allowing for the shorter time and the greater dilution of the chloride.

Although the concentration of chlorine in most of these experiments is greater than that which is found in many mineral waters, it is noteworthy that solution of gold will take place with even a trace of chlorine (see experiment 2b), and without much doubt these reactions will go on also in the presence of only minute quantities of manganese oxides.

The solution of gold is probably most important, however, in the upper parts of the oxidized zones where most of the pyrite has been removed, for on oxidation pyrite yields ferrous sulphate, which tends to inhibit solution. The small amount of sulphuric acid which seems to be necessary for the reactions could easily be supplied, even above the zone where pyrite persists, by the leaching of basic iron sulphates, the formation of which tends to delay the downward migration of a portion of the sulphuric acid that is released where ferric sulphate alters to limonite.

PRECIPITATION OF GOLD WITH MANGANESE OXIDE.

Where it is held in solution as chloride, gold is readily precipitated by ferrous sulphate, which, as already stated, is formed by the action of acid on pyrite or other iron sulphides. If much manganese oxide is present, however, the ferrous sulphate is immediately oxidized to ferric sulphate, which does not precipitate gold from solutions in which it is held as chloride. In the presence of manganese oxides, therefore, gold is not only dissolved in acid solution, but the conditions under which it is precipitated may be delayed. Gold may be carried in acid solution so long as the higher oxides of manganese are present.

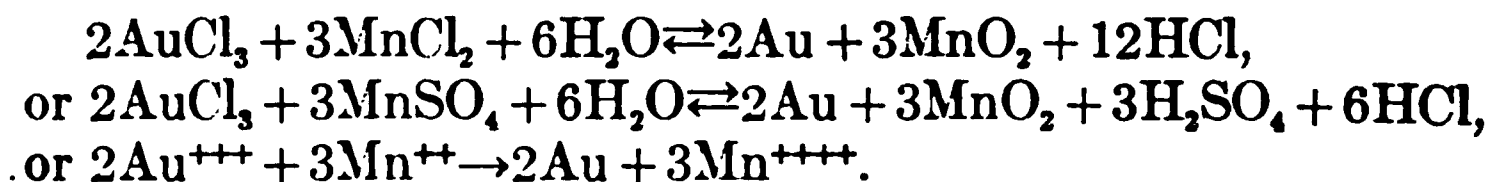
In many gold deposits manganese oxides and gold are intimately associated and without doubt have been precipitated together. This association is by no means uncommon. The deposits of the Camp Bird mine,¹ of the Tomboy mine,² of the Amethyst vein at Creede, Colo.,³ of the Dahlonega mines, in Georgia,⁴ and of mines at Philipsburg, Mont.,⁵ are noteworthy examples.⁶

These relations indicate a process by which gold is precipitated along with manganese oxide in a reducing environment. On this point Mr. R. C. Wells offers the following statement:

The precipitation of manganese will occur more and more as the solution loses its acidity. It is well established that manganous salts in an acid environment are very stable; but in neutral or alkaline solutions they oxidize more vigorously, one stage of their oxidation being the manganic salt, which hydrolyzes into $Mn_2O_3 \cdot H_2O$ (manganite) with even greater ease than ferric salts into limonite.

In these ways the migration of an acidic solution would result in the transportation of both gold and manganese. But in a region of basic, alkaline, and reducing environment the manganese would be reprecipitated, the free acid neutralized, the chlorine absorbed by the bases and removed, and owing to the accumulation of the ferrous or other reducing salts the gold would be reprecipitated.

Some experiments in the precipitation of gold have recently been made by Mr. A. D. Brokaw, who offers me the following data in advance of publication. Into an acid solution in which gold was dissolved in the presence of manganese a crystal of calcite was introduced. On decreasing acidity of the solution with calcium carbonate gold was precipitated with manganese oxide on the surface and in the cleavage cracks of the calcite crystals. The reactions may be stated as follows:



¹ Ransome, F. L., A report on the economic geology of the Silverton quadrangle, Colorado: Bull. U. S. Geol. Survey No. 182, 1901, p. 202.

² Purington, C. W., Preliminary report on the mining industries of the Telluride quadrangle, Colorado: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1908, pp. 838-841.

³ Emmons, W. H., and Larsen, E. S., A preliminary report on the geology and ore deposits of Creede, Colo.: Bull. U. S. Geol. Survey No. 530, 1913, p. 58.

⁴ Laney, F. B., oral communication.

⁵ Emmons, W. H., and Calkins, F. C., Geology and ore deposits of Philipsburg, Mont.: Prof. Paper U. S. Geol. Survey No. 78 (in press).

⁶ See also Tolman, C. F., jr., Secondary sulphide enrichment of ores: Min. and Sci. Press, vol. 106, 1913, p. 41.

These reactions indicate processes by which gold held in acid solution in the presence of manganese salts may be precipitated in the deeper zones, together with manganese oxides, when the solutions reacting on alkaline minerals lose acidity. In general, however, the mangiferous gold ores that are formed in the lower zones of gold deposits carry more manganese than gold and a larger proportion of manganese than would be precipitated by the reaction above indicated. Possibly some of the manganese is precipitated on neutralization as hydroxide, which oxidizes almost immediately on being exposed to air, or perhaps as some other manganese compound that is soluble in acid but insoluble in alkaline solutions.

In some deposits there is evidence that gold has been dissolved and reprecipitated in the surficial zone, yet the secondary gold ore carries no manganese, or at least not more than a trace of manganese compounds. Such relations, according to Ransome,¹ are indicated by the gold veins of Farncomb Hill, in the Breckenridge district, Colorado, where the secondary gold ore is almost free from manganese. It has been stated that gold may be precipitated from solutions in which it is dissolved as chloride either by the neutralization of the solution or by ferrous sulphate generated by the action of the solution on pyrite. Ferrous sulphate will precipitate gold even from strongly acid solutions in which manganese would still remain in solution. It follows that manganese might not be precipitated with gold from acid solutions even where manganese dioxide has supplied conditions for its solution in chloride waters; but from neutralized solutions the gold and manganese would go down perhaps simultaneously. Gold is precipitated from chloride solution also by native metals, sulphides, organic matter, and many other materials.

The size of the particles of gold has little value as a means of determining its origin. The gold deposited by the reduction or the neutralization of mangiferous compounds may be finely pulverulent or it may form nuggets of considerable size. Mr. Brokaw, in the experiments cited above, where gold and manganese were precipitated on calcite, obtained masses of gold distinctly visible without a hand lens.

In some deposits the purity or fineness of the gold may afford a means by which primary may be distinguished from secondary gold. In a deposit in northern Nevada the rich gold ore is electrum, a light-colored natural alloy of gold and silver. On this, deposited presumably from cold solutions, are small masses of dark-yellow gold which is apparently of great fineness. This criterion should be applied with caution, however, and the relations should be established independently for each particular deposit, for under some conditions doubtless secondary gold and silver are precipitated together.

¹ Ransome, F. L., *Geology and ore deposits of the Breckenridge district, Colorado*: Prof. Paper U. S. Geol. Survey No. 75, 1911, p. 170.

SOURCES OF MANGANESE IN GOLD DEPOSITS.

It has been shown that the solution of gold depends on the presence of chlorine in the mineral waters, and the distribution of chlorine has been discussed briefly on page 66. But chlorine is an efficient solvent of gold only when in the "nascent" state, and under natural conditions nascent chlorine is released principally by manganese oxides. The sources and distribution of manganese are therefore of some importance in connection with the concentration of gold. The important manganese minerals are listed below.

Pyrolusite.....	MnO ₂ .
Psilomelane.....	MnO ₂ .2H ₂ O.
Manganite.....	Mn ₂ O ₃ .H ₂ O.
Manganosite.....	MnO.
Pyrochroite.....	Mn(OH) ₂ .
Szomikite.....	MnSO ₄ .H ₂ O.
Mallardite.....	MnSO ₄ .7H ₂ O.
Apjohnite.....	MnSO ₄ .Al ₂ (SO ₄) ₃ .24H ₂ O.
Alabandite.....	MnS.
Hauerite.....	MnS ₂ .
Manganostibnite.....	9MnO.Sb ₂ O ₃ .
Manganiferous calcite.....	(Ca,Mn)CO ₃ .
Rhodochrosite.....	MnCO ₃ .
Rhodonite.....	MnSiO ₃ .
Amethystine quartz.	
Many rock-making silicates.	

The commonest sources of manganese are probably the silicates of iron and magnesia. Manganese is more abundant in basic than in acidic rocks. The average of 1,038 determinations of igneous rocks¹ is 0.10 per cent manganese protoxide (MnO), while some contain more than 1.0 per cent.

Amethystine quartz is an important source of manganese in some auriferous deposits. It is an abundant gangue mineral at Creede, Colo., where it is the chief primary source of manganese. Some of the shipments of the ores from the Amethyst lode contain 3 or 4 per cent of manganese.

Rhodonite is closely allied to the pyroxenes in crystallization, but, unlike them, it occurs as a gangue mineral formed by ascending waters at moderate depths. It is found in ore of the Camp Bird, Tomboy, and other mines of the San Juan, Colo., in the silver-bearing veins of Butte, Mont., at Philipsburg, Mont., and at many other places.

Rhodochrosite is more common in mines of the United States than rhodonite. It is present in many veins of the San Juan, Colo., at Butte and Philipsburg, Mont., at Austin, Nev., and in many other western districts.

¹ Clarke, F. W., The data of geochemistry, 2d ed.: Bull. U. S. Geol. Survey No. 491, 1911, p. 27.

Manganiferous calcite, an isomorphous compound of rhodochrosite and calcite, is a source of abundant manganese in many later Tertiary deposits in Nevada, Montana, and Colorado. It is probably present in certain Mesozoic copper deposits of Shasta County, Cal., where, according to Graton,¹ it occurs in the oxidized zone.

Rhodonite is considered primary in all its occurrences and rhodochrosite is deposited in the main from ascending hot solutions also, but in some occurrences it has been regarded as a secondary deposit from cold solutions.

Manganiferous precious-metal ores are in general deposited at moderate depths. Consequently they are common in middle or late Tertiary deposits of western North America but very rare indeed in contact-metamorphic deposits in the California gold veins and in deposits formed at equal or greater depths.²

The sulphates of manganese are soluble and do not accumulate in veins to any important extent; all are secondary. The oxides and hydrous oxides, which are very numerous, are the products of weathering of all manganese compounds. None of them are known to be deposited by ascending hot waters except near the orifices of hot springs.

The sulphides of manganese are exceedingly rare. Alabandite has been found in the gold mines of Nagyag, in Transylvania; at Gersdorf, near Freiberg, Saxony; on Snake River, Summit County, Colo.; at Tombstone, Ariz.; and at a few other places. Hauerite is still less common. I can find no record of its occurrence in the United States. The obvious explanation for the rarity of manganese sulphides in nature is their comparatively great solubility even in very dilute acids, and their tendency to oxidize on exposure to air.

PLACERS AND OUTCROPS.

Those deposits in which enrichment in gold is believed to have taken place are, almost without exception, manganiferous. Inasmuch as enrichment is produced by the downward migration of the gold instead of by its superficial removal and accumulation, it should follow that both gold placers and outcrops rich in gold would generally be found in connection with nonmanganiferous deposits; and this inference is believed to be confirmed by field observations.³ Placer deposits are in general associated with nonmanganiferous lodes, and such lodes are generally richer at the outcrops and in the oxidized

¹ Graton, L. C., The occurrence of copper in Shasta County, Cal.: Bull. U. S. Geol. Survey No. 430, 1910, p. 100.

² Emmons, W. H., The agency of manganese in the superficial alteration and secondary enrichment of gold deposits in the United States: Bull. Am. Inst. Min. Eng. No. 46, 1910, pp. 813, 814-816.

³ Idem, pp. 767-837; Jour. Geology, vol. 19, 1911, pp. 15-46.

zones than in depth, the enrichment being due, in the main, to a removal of the material associated with gold. Even under favorable conditions, however, gold is generally dissolved less readily than copper or silver and precipitated more readily than either. Consequently its enriched ores are likely to be found nearer the surface. In a manganiferous calcite gangue gold may accumulate at the very outcrop, for the solutions could not long remain acid if passing through alkaline rocks. Some placer deposits even are associated with gold lodes having a manganiferous calcite gangue.

CONCENTRATION IN THE OXIDIZED ZONE.

The concentration of gold in the oxidized zone near the surface, where the waters remove the valueless elements more rapidly than gold,¹ is an important process in lodes which do not contain manganese or in manganiferous lodes in areas where the waters do not contain appreciable chloride. In the oxidized zone in some mines it is difficult to distinguish the ore which has been enriched by this process from ore which has been enriched lower down by the solution and precipitation of gold and which, as a result of erosion, is now nearer the surface. It can not be denied that fine gold migrates downward in suspension, but this migration probably does not occur to an important extent in the deeper part of the oxidized zone. If the enrichment in gold is due simply to the removal of other constituents it is important to consider the volume relations and the mass relations before and after enrichment and to compare them with those now prevailing. It can be shown that the enriched ore in some lodes occupies about the same space that it occupied before oxidation. Let it be supposed that a pyritic gold ore has been altered to a limonite gold ore, and that gold has been neither removed nor added. Limonite (specific gravity 3.6 to 4), if it is pseudomorphic after pyrite (specific gravity 4.95 to 5.10) and if not more cellular, weighs about 75 per cent as much as the pyrite. In those specimens which I have broken cellular spaces occupy in general about 10 per cent of the volume of the pseudomorph. With no gold added, the secondary ore should not be more than twice as rich as the primary ore, even if a large factor is introduced to allow for silica removed and for cellular spaces developed.

Rich bunches of ore are much more common in the oxidized zone than in the primary sulphides of such lodes. They are present in some lodes which carry little or no manganese in the gangue and which below the water level show no deposition of gold by descending solutions. Some of them are doubtless residual pockets of rich ore that were richer than the main ore body when deposited as sulphides,

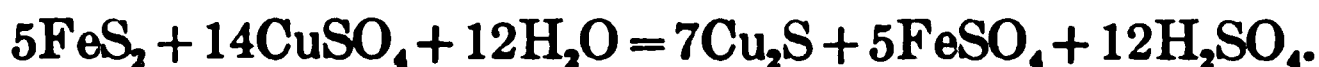
¹ Rickard, T. A., The formation of bonanzas in the upper portions of gold veins: *Trans. Am. Inst. Min. Eng.*, vol. 31, 1902, pp. 198-220.

but others are very probably ores to which gold has been added in the process of oxidation near the water table by the solution and precipitation of gold in the presence of the small amount of manganese contributed by the country rock. In view of the relations shown by the chemical experiments it is probable that a very little manganese will accomplish the solution of gold, but it requires considerably more manganese to form appreciable amounts of the higher manganese compounds that delay the deposition of gold, suppressing its precipitation by ferrous sulphate. In the absence of larger amounts of the higher manganese compounds the gold would probably be precipitated almost as soon as the solutions encountered the zone where any considerable amount of pyrite or other sulphides was exposed in the partly oxidized ore; for oxygenated solutions dissolve pyrite, and even traces of the ferrous sulphate formed in the oxidizing reactions precipitate gold almost immediately. Many other sulphides precipitate gold very readily. From this it follows that deposits showing only traces of manganese, presumably supplied from the country rock, are not enriched far below the zone of oxidation.

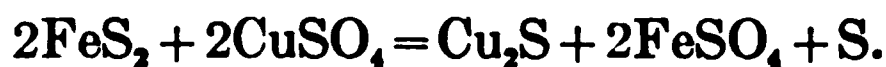
VERTICAL RELATION OF DEEP-SEATED ENRICHMENT IN GOLD TO CHALCOCITIZATION.

In several of the great copper districts of the West gold is a valuable by-product. In another group of deposits, mainly of Tertiary age and younger than the copper deposits, silver and gold are the principal metals, and copper, when present, is only a by-product. But in some of these precious-metal ores chalcocite is nevertheless the most abundant metallic mineral and constitutes several per cent of the vein matter. In many ores it forms a coating over pyrite or other minerals. Some of this ore, appearing in general not far below the water table, is fractured, spongy quartz coated with pulverulent chalcocite. A part of it contains a good deal of silver and more gold than the oxidized ore or the deeper-seated sulphide ore. Clearly the conditions that favor chalcocitization are favorable also to the precipitation of silver and gold.

The replacement of pyrite by chalcocite is, according to Stokes,¹ as follows:



This reaction is considered by Spencer² as comprising several stages, which may be indicated as follows:



¹ Stokes, H. N., Experiments on the action of various solutions of pyrite and marcasite: *Econ. Geology*, vol. 2, 1907, p. 22.

² Spencer, A. C., Chalcocite deposition: *Jour. Washington Acad. Sci.*, vol. 3, 1913, p. 73.

The reactions may differ as to details, but without much doubt ferrous sulphate and acid are set free. Attendant reactions confirm this statement, for if calcite is present gypsum is formed by the reaction of sulphuric acid on lime carbonate, and if the wall rocks are sericitic kaolin is formed by the reaction of the acid with potassium-aluminum silicate, the potash going into solution as sulphate. The abundant ferrous sulphate must quickly drive the gold from solution, and it apparently follows that there may be no appreciable enrichment of gold below the zone where chalcocitization is the prevailing process. In deposits like disseminated chalcocite in porphyry, where the chalcocite occurs in flat-lying zones conforming with the present surface, where the ore from which chalcocite was derived carried gold, and where suitable solvents were provided, the gold, at least in the upper part of the chalcocite zone, should be rather evenly distributed and should increase and decrease in quantity with the chalcocite of the secondary ore. According to report there is a fairly constant ratio between copper and gold in the disseminated deposits at Ely, Nev., and Bingham, Utah. In the copper deposits at Rio Tinto, Spain,¹ the secondary ores between the gossan and the primary sulphides carried high values in gold and silver. In view of the chemical relations it would appear that whatever gold and silver are present below a chalcocitized pyrite ore are, without much doubt, primary.

Gold and silver are commonly associated in their deposits, and an exact knowledge of the solution and precipitation of the two metals in experiments where both are present would have great practical value. Although gold is dissolved in chloride solutions, silver chloride is but slightly soluble, and high concentration of the two metals could not exist in the same solution. There is so little exact information regarding the solubilities of gold chloride and silver chloride in solutions containing both metals that a discussion of their relations is little more than speculation, yet certain data should be considered in this connection. Silver chloride is slightly soluble in water, and silver may be held in small concentration in solutions in which gold also is dissolved. A mine water from the Comstock lode, according to Reid,² carried 188 milligrams of silver and 4.15 milligrams of gold in a ton of solution. Since ferrous sulphate and certain sulphides precipitate both gold and silver from acid solution, alloys of these metals might form as secondary minerals. Since ferrous sulphate is released in the chalcocitization of pyrite, the secondary ores of gold and silver could be deposited simultaneously with chalcocite.

¹ Vogt, J. H. L., Problems in the geology of ore deposits, in Pošepný, Franz, The genesis of ore deposits, 1902, p. 676.

² Reid, J. A., The structure and genesis of the Comstock lode: Bull. Dept. Geology Univ. California, vol. 4, No. 10, 1905, p. 193.

GOLD AND SILVER TELLURIDES.

Petzite, sylvanite, krennerite, and calaverite are tellurides of gold and silver, the precious metals being present in varying proportions. All are regarded as primary. Since hydrogen telluride (H_2Te) is made by the action of acids on metallic tellurides, and since gold and silver tellurides are insoluble,¹ telluride enrichment appears to be within the bounds of probability, but no clearly defined examples of secondary gold-silver tellurides are known to me.

SOME CHEMICAL RELATIONS AND MINERALS OF LEAD.

PRINCIPAL LEAD MINERALS.

The chemical composition of the principal lead minerals is given below:

Lead.....	Pb.
Minium.....	$2\text{PbO}.\text{PbO}_2$.
Massicot.....	PbO.
Plattnerite.....	PbO_2 .
Pyromorphite.....	$3\text{Pb}_3\text{P}_2\text{O}_8.\text{PbCl}_2$.
Cotunnite.....	PbCl_2 .
Plumbojarosite.....	$\text{Pb}[\text{Fe}(\text{OH})_2]_6[\text{SO}_4]_4$.
Leadhillite.....	$4\text{PbO}.\text{SO}_3.2\text{CO}_2.\text{H}_2\text{O}$.
Anglesite.....	PbSO_4 .
Cerussite.....	PbCO_3 .
Galena.....	PbS.

SOLUBILITIES OF LEAD COMPOUNDS.

The solubilities of several lead compounds, as determined by Kohlrausch, are as follows:

PbSO_4	PbCl_2	PbCO_3	$\text{Pb}(\text{NO}_3)_2$
0.041 .00013	14.9 .06	0.001 .00003	516.6 1.4

The upper number in each column shows the number of grams of the anhydrous salt held in solution in a liter of water at 18°C .; the lower number shows the molar solubility or the number of mols contained in a liter of the saturated solution.²

The common salts of lead are bivalent; the rarer ones are quadrivalent. As shown by the table above, all the common salts have low solubilities except the nitrates, which are not important in processes of sulphide enrichment. Freshly precipitated lead sulphide is dissolved sparingly in cold water, its solubility being 0.0000036 mol in a liter. (See p. 57.)

¹ Smith, Alexander, *Introduction to inorganic chemistry*, rev. ed., 1910, p. 403.

² *Idem*, p. 544.

The native metal and the oxides of lead (minium, plattnerite, and massicot) are of rare occurrence.

Lead chloride is moderately soluble, so cotunnite, PbCl_2 , does not accumulate in the oxidized zones of lead deposits. Lead chlorophosphate, pyromorphite, is much more common. Lead carbonate is very sparingly soluble, so cerusite, PbCO_3 , is a comparatively stable mineral, as is the sulphate, anglesite, PbSO_4 . Although the solubility of the sulphate is low, it is nevertheless appreciable, as is indicated in quantitative analysis, for in order to prevent loss a precipitate of lead sulphate formed in sulphuric acid is washed with alcohol rather than with water. The transfer of lead as sulphate in small yet appreciable quantities was shown also in the experiments of Buehler and Gottschalk (p. 49).

As would be supposed from consideration of the relatively low solubility of its sulphate, lead is not extensively transferred in cold acid sulphate waters. R. C. Wells has shown that galena reacts with weak solutions of sulphuric acid more readily than pyrite or chalcopyrite, the reaction being attended by the liberation of hydrogen sulphide (p. 59). Whether oxygen is necessary for the solution of lead sulphide, as it is for the solution of copper sulphide, I am unable to state. The salts that form under natural conditions have low solubilities and coat the sulphides, inhibiting or at least retarding further action. Consequently lead sulphide dissolves slowly. It is dissolved in acid to only a slight extent and, like copper sulphide, would be deposited in an acid environment. Although several primary minerals contain lead,¹ galena is the only one of these that is at all common. All the other minerals listed above—the chlorides, oxides, sulphates, and carbonates—are probably formed as secondary minerals only.

The paragenetic evidence that galena is commonly precipitated below the water level by the reduction of acid sulphate waters is not abundant, but in the greater number of its occurrences galena is regarded as primary. Lead, like gold, migrates very slowly in cold solutions.

OCCURRENCE OF THE LEAD MINERALS.

Native lead.—Although native lead is found in a number of lead deposits,² it is in very few so abundant as to become an important ore mineral. It is probably formed by reduction of oxygen salts of lead.

Pyromorphite, $3\text{Pb}_3\text{P}_2\text{O}_8 \cdot \text{PbCl}_2$, is the principal metallic phosphate and is the only common lead mineral containing chlorine. It is an alteration product of lead ores that are exposed to waters carrying

¹ Clarke, F. W., *The data of geochemistry*, 2d ed.: Bull. U. S. Geol. Survey No. 491, 1911, p. 646.

² Hintze, Carl, *Handbuch der Mineralogie*, vol. 1, pp. 333–334.

chlorine and phosphoric acid. At Philipsburg, Mont., at Creede, Colo., and in the Cœur d'Alene district, Idaho,¹ pyromorphite is characteristic of upper parts of the zones of oxidation. In these deposits it is associated with limonite and commonly carries silver, possibly as finely divided cerargyrite.

Cotunnite, PbCl_2 , as already stated, is a comparatively rare mineral. It has been identified at few places, one of them in the crater of Vesuvius. Lead chloride is more soluble than lead chlorophosphate. The accumulation of the chloride in the oxidized zones of lead deposits is limited probably by the amount of phosphate available in the natural solutions.

Minium, *massicot*, and *plattnerite*, all oxides of lead, are comparatively rare. All are secondary.

Leadhillite, $4\text{PbO} \cdot \text{SO}_3 \cdot 2\text{CO}_2 \cdot \text{H}_2\text{O}$, a basic sulphatocarbonate of lead, is found in ores altered by surface agencies and is probably confined to such deposits.

Anglesite, PbSO_4 , is known only as an alteration product. Most commonly it forms from galena, but it has been noted also as an alteration product of *guitermanite*,² an arsenic sulphide of lead, and also of other minerals. According to Penrose,³ the sulphate forms as an intermediate product when galena is altered to *cerusite*, and at Leadville, Colo., S. F. Emmons⁴ found that thin crusts of *anglesite* occurred between galena and the crust of carbonate which enveloped it. It is associated with carbonates and sulphide in oxidized zones of deposits at Bingham, Utah.⁵ Boutwell describes an interesting specimen consisting of a kernel of galena covered with *anglesite*, which in turn is coated with *cerusite*, upon which is deposited yellow lead oxide, probably *massicot*. In the sideritic lead ores of the Cœur d'Alene district, Idaho, according to Ransome,⁶ no *anglesite* has been detected, but the carbonate appears to form without the intermediate sulphate.

Anglesite is much more common than *cerusite* in the oxidized lead ores of Lake City, Colo.,⁷ and is of considerable economic value in this district. In the upper 100 feet of the Moro vein it is particularly abundant. It is common also in the lead ores at Creede, Colo.⁸

¹ Ransome, F. L., and Calkins, F. C., The geology and ore deposits of the Cœur d'Alene district, Idaho: Prof. Paper U. S. Geol. Survey No. 62, 1908, p. 103.

² Ransome, F. L., A report on the economic geology of the Silverton quadrangle, Colo.: Bull. U. S. Geol. Survey No. 182, 1901, p. 87.

³ Penrose, R. A. F., Superficial alteration of ore deposits: Jour. Geology, vol. 2, 1894, p. 297.

⁴ Emmons, S. F., Geology and mining industry of Leadville, Colo.: Mon. U. S. Geol. Survey, vol. 12, 1886, p. 546.

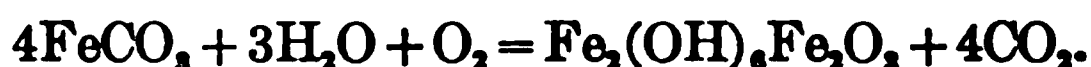
⁵ Boutwell, J. M., Economic geology of the Bingham mining district, Utah: Prof. Paper U. S. Geol. Survey No. 38, 1905, p. 113.

⁶ Ransome, F. L., and Calkins, F. C., op. cit., p. 132.

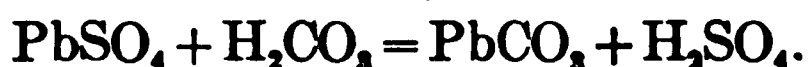
⁷ Irving, J. D., and Bancroft, Howland, Geology and ore deposits near Lake City, Colo.: Bull. U. S. Geol. Survey No. 478, 1911, p. 61.

⁸ Emmons, W. H., and Larsen, E. S., Geology and ore deposits of Creede, Colo.: Bull. U. S. Geol. Survey (in preparation).

Cerussite, PbCO_3 , is unknown as a primary mineral but is common as an alteration product. It was abundant in the upper levels of mines at Bingham, Utah, where it was generally associated with anglesite and galena.¹ It is an important ore mineral of the deposits at Leadville,² in some veins of the Cœur d'Alene district,³ at Creede, and in several other lead-ore districts. It is most abundant in deposits where the country rock is limestone but is not limited to such deposits. Very commonly the carbonate replaces galena metasomatically. According to Penrose⁴ lead sulphate may form intermediately between the sulphide and carbonate, and its formation is favored by the lower solubility of the carbonate. (See p. 135.) In the Cœur d'Alene district the change is not everywhere a metasomatic replacement for, according to Ransome,⁵ cerussite is common in little vugs or crevices in the sulphides, where it is formed on unaltered galena by solutions that have percolated downward from the oxidized zone. As stated by Ransome, the oxidation of siderite may supply carbonate for cerussite. The reaction is—



With carbonic acid in solution cerussite may form as follows:



Galena, PbS , is a "persistent" mineral—a mineral formed under many natural conditions. The most important deposits of galena in the United States are the disseminated ores of southeastern Missouri and the lead-silver ores of the Cœur d'Alene district, Idaho.⁶ The galena in Missouri is nearly pure lead sulphide, has a perfect cleavage, and is generally in cubic crystals; the galena of the Cœur d'Alene district contains appreciable silver, is generally not so well crystallized, and has a much less perfect cleavage, so that a freshly broken fracture resembles that of steel and the mineral is called "steel galena" by the miners. Some antimonial galena has a similar fracture. Some galena is rich in silver, which is probably present as finely divided argentite, Ag_2S .

The stability of galena in the oxidized zone has already been mentioned. The relative insolubility of galena in natural waters is shown by the experiments of Buehler and Gottschalk (p. 49), and is confirmed abundantly by observations in the oxidized zones of deposits. Galena is commonly found in sluice boxes of placer mines

¹ Boutwell, J. M., Economic geology of the Bingham mining district, Utah: Prof. Paper U. S. Geol. Survey No. 38, 1905, p. 112.

² Emmons, S. F., Geology and mining industry of Leadville, Colo.: Mon. U. S. Geol. Survey, vol. 12, 1886, p. 546.

³ Ransome, F. L., and Calkins, F. C., op. cit., p. 92.

⁴ Penrose, R. A. F., Superficial alteration of ore deposits: Jour. Geology, vol. 2, 1894, p. 297.

⁵ Ransome, F. L., and Calkins, F. C., op. cit., p. 112.

⁶ Idem, p. 91.

and is plowed up in the fields of the southwestern Wisconsin zinc district. Even in districts where the climate is comparatively moist, such as the Breckenridge and Cœur d'Alene districts, galena is found at the very outcrops of some ore veins.¹

In the Cœur d'Alene district, according to Ransome and Calkins, there is little evidence of enrichment of either silver or lead by cold solutions. In the Breckenridge district² the characteristic ore of the upper levels is argentiferous galena, more or less altered to cerusite, whereas in the lower levels sphalerite and pyrite become increasingly abundant, suggesting enrichment in the upper levels by addition of lead or by subtraction of zinc, or by both.

At Leadville, Colo., according to Blow,³ stringers of galena rich in silver penetrate the limestone below the bodies of carbonate ores. As noted by Vogt,⁴ and also by Finlayson,⁵ the pyritic ore of the Rio Tinto mine in Spain is cracked and is generally seamed with deposits of chalcocite, bornite, chalcopyrite, and galena, and the galena, according to Finlayson, is commonly of most recent formation. It is not stated, however, that the galena was deposited by descending waters.

Weed⁶ has described secondary galena from the sulphide zone at Neihart, Mont., where it is associated with zinc blende and incrustated with polybasite; and Irving and Bancroft⁷ state that some of the galena of the Lake City district, Colorado, is without doubt connected genetically with oxidation processes. In that district a gray coating of a lead compound, thought to be galena, occurs in cracks of shattered sphalerite and covers its exposed surfaces. Possibly the gray sphalerite observed in many deposits of the West owes its color to such a veneer of galena.

A survey of the literature of lead deposits for examples giving evidence of considerable secondary precipitation of lead sulphide in lode ores has not been very fruitful of results. On the other hand, there is much evidence of migration of lead in cold carbonated solution and of its precipitation as sulphide in the important lead and zinc ores of the Mississippi Valley. These processes, as already stated, do not come within the scope of this investigation.

¹ Ransome, F. L., *Geology and ore deposits of the Breckenridge district, Colorado*: Prof. Paper U. S. Geol. Survey No. 75, 1911, p. 166. Ransome, F. L., and Calkins, F. C., *Geology and ore deposits of the Cœur d'Alene district, Idaho*: Prof. Paper U. S. Geol. Survey No. 62, 1908, p. 133.

² Ransome, F. L., *Criteria of downward sulphide enrichment*: *Econ. Geology*, vol. 5, 1910, p. 206.

³ Blow, A. A., *The ore chutes and recent developments of Iron Hill, Leadville, Colo.*: *Trans. Am. Inst. Min. Eng.*, vol. 18, 1890, p. 169.

⁴ Vogt, J. H. L., *Das Huelva-Kiesfeld*: *Zeitschr. prakt. Geologie*, July, 1899, p. 249.

⁵ Finlayson, A. M., *The pyritic deposits of Huelva, Spain*: *Econ. Geology*, vol. 5, 1910, p. 421.

⁶ Weed, W. H., *The enrichment of gold and silver veins*, in Poëpny, Franz, *The genesis of ore deposits*, 1902, p. 485.

⁷ Irving, J. D., and Bancroft, Howland, *Geology and ore deposits near Lake City, Colo.*: *Bull. U. S. Geol. Survey No. 478*, 1911, p. 97.

SOME CHEMICAL RELATIONS AND MINERALS OF ZINC.

PRINCIPAL ZINC MINERALS.

The chemical composition of the principal zinc minerals is shown below:

Goslarite.....	$\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$.
Smithsonite.....	ZnCO_3 .
Calamine.....	$\text{Zn}_2\text{H}_2\text{SiO}_5$ or $2\text{ZnO} \cdot \text{SiO}_2 \cdot \text{H}_2\text{O}$.
Willemite.....	Zn_2SiO_4 .
Hydrozincite.....	$\text{ZnCO}_3 \cdot 2\text{ZnO} \cdot \text{H}_2\text{O}$ or $3\text{ZnO} \cdot \text{CO}_2 \cdot 2\text{H}_2\text{O}$.
Aurichalcite.....	$2(\text{Zn}, \text{Cu})\text{CO}_3 \cdot 3(\text{Zn}, \text{Cu})\text{O} \cdot \text{H}_2\text{O}$.
Sphalerite.....	ZnS .
Wurtzite.....	ZnS .

SOLUBILITIES OF ZINC COMPOUNDS.

The solubilities of several zinc salts determined by Kohlrausch are stated below:

ZnSO_4 .	ZnCl_2 .	ZnCO_3 .	$\text{Zn}(\text{NO}_3)_2$.
531.2 3.1	2039. 9.2	0.04 ? .0003 ?	1178. 4.7

The upper number in each column shows the number of grams of the anhydrous salt held in solution in a liter of water at 18° C.; the lower number shows the molar solubility or the number of mols contained in a liter of the saturated solution.

Zinc is bivalent in all its compounds. The sulphate and chloride are very soluble and the carbonate is more soluble than carbonate of lead. A liter of pure water dissolves at ordinary temperature and pressure 0.0000706 mol of freshly precipitated zinc sulphide. (See p. 59.) The principal primary zinc mineral is the isometric form, sphalerite. Wurtzite, the hexagonal form of zinc sulphide, is comparatively rare. In some occurrences the primary zinc minerals are oxides, such as franklinite, zincite, and gahnite, but as these are rare or absent in sulphide deposits, they are not considered here.

As zinc sulphide is easily dissolved in sulphuric acid sphalerite would not form in a highly acid solution. If, through reactions with the wall rock, the solution should become feebly acid or neutral, then zinc sulphide could be precipitated. Allen and Crenshaw state that sphalerite is precipitated from acid as well as from alkaline solutions, but that wurtzite is precipitated only from acid solutions and is probably always secondary.¹ Since zinc sulphide is one of the most soluble of the common sulphides it could not replace sulphides of

¹ Allen, E. T., and Crenshaw, J. L., The sulphides of zinc, cadmium, and mercury; their crystalline forms and genetic conditions: Am. Jour. Sci., 4th ser., vol. 34, 1912, p. 359.

copper, silver, or lead. Possibly it could replace pyrite, marcasite, or pyrrhotite under certain conditions, but no examples of its pseudomorphs after these minerals are known to me. It is itself replaced by chalcocite and covellite and probably by argentite and galena.

There is every reason to suppose that zinc sulphide in carbonate rocks in the zinc deposits of the upper Mississippi Valley in southwestern Wisconsin has been dissolved by oxygenated waters and has been reprecipitated as sulphide in large amounts where the solutions were in contact with reducing agents.

Secondary zinc blende has been found in western ore deposits in other than limestone, but so far as the records show its occurrence in western deposits is exceedingly rare. Large quantities of zinc are undoubtedly dissolved from the outcrops and oxidized zones of deposits in which it occurs as sulphide and are passed as sulphate downward, below the water level. To account for its disposition is one of the most perplexing problems in the study of mineral genesis. Doubtless much of it escapes to the surface and is scattered, yet many analyses of waters issuing from zinc deposits show much less zinc than would be expected. In two alkaline waters from sphaleritic deposits of Creede, Colo., no zinc is reported. In waters from several other deposits it is present in considerable amounts, but the quantity of it found in some of these is less than would be expected. In waters from several deposits at Ducktown, Tenn., the zinc in solution is less than the copper, although the sulphide deposits contain as much zinc as copper and copper is now being precipitated. Some sludges deposited by mine waters where they issue to the air contain considerable zinc; others contain practically none. Zinc salts do not hydrolyze so readily as ferric salts when exposed to air. With carbon dioxide they form smithsonite, hydrozincite, and aurichalcite, but these compounds are generally less abundant than hydrous iron oxide.

OCCURRENCE OF THE ZINC MINERALS.

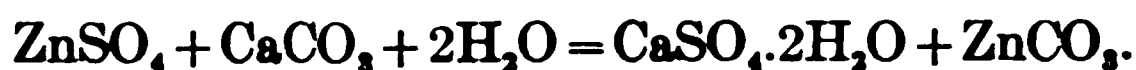
Goslarite, hydrated zinc sulphate, occurs on the walls of some mine workings as a white filiform or mosslike efflorescence, which soon disintegrates to powder in the air. Owing to the high solubility of zinc sulphate in water, goslarite is comparatively rare in most districts, though it is abundant in some, as at Creede, Colo., and Butte, Mont. Weed states that zinc sulphate is carried by the moisture of the air circulating in mine openings.¹

Zinc chloride is even more soluble than the sulphate and is unknown as a natural mineral.

Smithsonite, ZnCO_3 , is commonly found in the oxidized zones of zinc-bearing veins. It is most abundant in deposits in limestone.

¹ Weed, W. H., *Geology and ore deposits of the Butte district, Montana*: Prof. Paper U. S. Geol. Survey No. 74, 1912, p. 99.

It has not been reported as a primary mineral in deposits formed by hot ascending waters. Where zinc-sulphate waters attack limestone, smithsonite is deposited, calcium sulphate, the most soluble salt, going into solution. The reaction may be stated as follows:



The calcium sulphate precipitated as gypsum may remain with smithsonite or may be carried away in solution, since it is fairly soluble in cold water (2.0 grams in a liter at 18° C.).

Calamine, $\text{H}_2\text{Zn}_2\text{SiO}_5$, is commonly associated with smithsonite in the oxidized zones of zinciferous ores. It is not known as a primary mineral of ore veins deposited from hot solutions.

Willemite, Zn_2SiO_4 , the anhydrous silicate, is much less common than calamine. It is abundant in the primary ores of Franklin Furnace, N. J.,¹ but is not reported as occurring in the secondary ores at many zinc deposits. It is noted as an alteration product, however, at Morenci, Ariz.,² and appears in considerable quantities at Tres Hermanas, N. Mex.,³ where it is probably derived from zinc blende by oxidation.

Hydrozincite, the basic carbonate, occurs commonly in altered ores.

Aurichalcite, a basic carbonate of zinc and copper, is deposited by cold solutions, generally as drusy incrustations.

Sphalerite is the most abundant primary ore of zinc. A few observations on the occurrence of secondary sphalerite are noteworthy. According to Blow,⁴ it seems probable that at Leadville, Colo., a large proportion of the zinc removed from the carbonate zone by surface waters was redeposited as sulphide in the lodes just below the line of complete oxidation and that redeposition has kept pace with oxidation. In Shasta County, Cal., according to Graton,⁵ sphalerite that is later than pyrite is found in the sulphide zones of copper deposits in association with minerals that are probably in part of secondary origin. Veinlets of sphalerite cut rhodochrosite ore at Philipsburg, Mont. At Rio Tinto, according to Finlayson,⁶ some sphalerite is later than pyrite and chalcopyrite. At Breckenridge, Colo., according to Ransome,⁷ some of the sphalerite is younger than the earliest period of deposition, although it can not be shown that it is a deposit of sulphate water. There is not much evidence, however, that zinc

¹ Spencer, A. C., Franklin Furnace folio (No. 161), Geol. Atlas U. S., U. S. Geol. Survey, 1908.

² Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, p. 111.

³ Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: Prof. Paper U. S. Geol. Survey No. 68, 1911, p. 294.

⁴ Blow, A. A., The ore chutes and recent developments of Iron Hill, Leadville, Colo.: Trans. Am. Inst. Min. Eng., vol. 18, 1890, p. 172.

⁵ Graton, L. C., The occurrence of copper in Shasta County, Cal.: Bull. U. S. Geol. Survey No. 430, 1910, pp. 71-111.

⁶ Finlayson, A. M., The pyritic deposits of Huelva, Spain: Econ. Geology, vol. 5, 1910, p. 417.

⁷ Ransome, F. L., Geology and ore deposits of the Breckenridge district, Colo.: Prof. Paper U. S. Geol. Survey No. 75, 1911, p. 169.

blende is precipitated as a secondary mineral along with copper, silver, and gold.

Wurtzite is probably a secondary mineral in the San Francisco district, Utah, according to B. S. Butler. In this connection the recent experiments of E. T. Allen and J. L. Crenshaw at the Carnegie Geophysical Laboratory are suggestive. Zinc sulphide was precipitated as wurtzite in acid but not in alkaline solutions.

SOME CHEMICAL RELATIONS AND MINERALS OF IRON.

PRINCIPAL IRON MINERALS.

The chemical composition of the principal iron minerals is shown below:

Limonite.....	$2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$.
Hematite.....	Fe_2O_3 .
Magnetite.....	Fe_3O_4 .
Melanterite.....	$\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$.
Jarosite.....	$\text{K}_2\text{O} \cdot 3\text{Fe}_2\text{O}_3 \cdot 4\text{SO}_4 \cdot 6\text{H}_2\text{O}$.
Siderite.....	FeCO_3 .
Ankerite.....	$\text{CaCO}_3 \cdot (\text{Mg}, \text{Fe}, \text{Mn})\text{CO}_3$.
Pyrite.....	FeS_2 .
Marcasite.....	FeS_2 .
Pyrrhotite.....	Fe_7S_8 .
Arsenopyrite.....	FeAsS .
Chalcopyrite.....	FeCuS_2 .
Bornite.....	Cu_5FeS_4 .

SOLUBILITIES OF IRON SALTS.

No comprehensive table showing the solubilities of iron salts determined under similar conditions is available to me. The solubilities of ferric and of ferrous salts differ greatly, and the experimental difficulties in determining the solubilities are considerable, owing to the changes that take place in the state of oxidation of iron. According to Atherton Seidell,¹ a liter of water at 20° C. dissolves 264.2 grams $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$; a liter of water saturated with CO_2 dissolves, at 6 to 8 atmospheres, 0.73 gram FeCO_3 ; a liter of water at 15° C. dissolves 400 grams of $\text{FeCl}_2 \cdot 4\text{H}_2\text{O}$ (Etard); a liter of water at 20° C. dissolves 478.8 grams FeCl_3 . (Total $\text{FeCl}_3 \cdot 12\text{H}_2\text{O}$ is 918.5 grams.)

NATURE AND RELATIONS OF THE IRON MINERALS.

Iron sulphides are comparatively unimportant as ores of iron. Some of the cinder obtained from burning pyrite for making acid is utilized in blast furnaces, and the gossans of some iron sulphide deposits also are smelted, but few of the iron ores of commerce are associated with sulphide deposits. The iron sulphides nevertheless

¹ Seidell, Atherton, *Solubilities of inorganic and organic substances*, New York, 1911.

play a most important part in the alteration and enrichment of deposits of the more valuable metals, and it is in that connection that they are considered here.

Most mine waters contain iron, and the facility with which ferric sulphate is changed to ferrous sulphate affords the most readily available index to the state of oxidation of the solutions. The chemical processes involved in the alteration of iron sulphides, the reduction of ferric sulphate, and the removal of acid to form inert sulphates below the water level have already been discussed.

Most of the iron sulphides contain more than enough sulphur to form iron sulphate on oxidation, and the remaining sulphate may be utilized to form sulphuric acid. Ferric sulphate readily hydrolyzes, forming basic ferric sulphate and subsequently ferric hydroxide, and each step sets free sulphuric acid. The property of hydrolysis of ferric salts is most important in connection with the superficial alteration and the enrichment of sulphide ores. It supplies a solvent for most of the metals; it generally results in the concentration of iron oxide at the surface, which may afford an indication that a deposit containing iron sulphide is below.

One function of basic ferric sulphate, which ultimately breaks down to form oxide, is to supply sulphate ion to solutions in the oxidized zone. Sulphates may thus be available even after all sulphides have disappeared.

As a result of the hydrolyzation of ferric sulphate the larger portion of the iron is generally fixed near the surface as iron oxide. Not all is so fixed, however, for the analyses of mine waters show that iron is almost universally present in the underground circulation. It has been stated above that iron passes below the water level, held in sulphuric acid solution mainly as iron sulphate; that the sulphate solution reacts on sulphides and gangue minerals; and that the acidity is reduced by forming inert sulphates, chiefly those of alkalies and alkaline earths. Along with such changes in acidity ferrous sulphate is produced by reduction of ferric sulphate.

It is doubtful whether ferric sulphate exists to any great extent far below the water level. In air a decrease in acidity favors hydrolyzation, but below the water level, where air is excluded, the decrease in acidity is attended by reduction of iron to ferrous state. Ferrous sulphate does not hydrolyze to precipitate iron oxide. Ferrous hydrate may be formed in neutral or alkaline environment. It is a light-colored salt which unites rapidly with free oxygen to form the brown ferric hydroxide. The mixture has a greenish appearance when distributed in a finely divided state through the precipitate.¹

In little cracks in sulphide ore, at considerable depths below the highly oxidized zone, small veinlets and putty-like masses of an

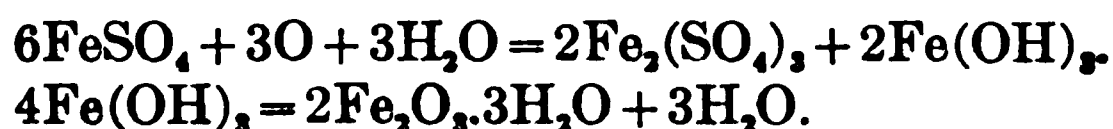
¹ Ostwald, Wilhelm, *The principles of inorganic chemistry* (trans. by Alex. Findlay), London, 1904,

iron oxide that is generally assumed to be limonite are conspicuous in many deposits. Such deposits of iron oxides in the Granite-Bimetallic vein at Philipsburg, Mont., are at least 500 feet below the zone of the highly oxidized ore. Some of them doubtless have formed since the mine was opened, at places where iron sulphate solutions issued from the vein and came in contact with air. Others may be due to deposition of iron oxide or basic ferric sulphate from suspension. (See pp. 73, 110.) Possibly some are the oxidation products of ferrous sulphate.

E. T. Allen has shown that a solution of hydrogen sulphide and ferric sulphate gives ferrous sulphate and sulphur, and in cold solutions of very low acidity ferrous sulphate with sulphur and hydrogen sulphide gives FeS_2 as pyrite and marcasite, the amount of each depending somewhat upon the acidity of the solution. It has been shown above that these conditions probably exist in the deeper zones in some deposits, but almost certainly they exist through a comparatively narrow chemical range. Consequently, the precipitation of secondary iron sulphides, although known in some, is probably subordinate in most deposits. Secondary chalcopyrite has been discussed with the ores of copper.

OCCURRENCE OF THE IRON MINERALS.

Limonite, $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$, is generally the most abundant of the iron oxides of the altered zones, which are mainly but not altogether hydrated oxides. It is precipitated from solution and commonly occurs as a pseudomorphous replacement of pyrite and other iron minerals. As shown in the equations stated on page 65, pyrite is converted in the vadose zone to ferrous sulphate. Since oxygen is present in excess, the ferrous salt is converted to ferric sulphate, which in turn hydrolyzes to ferric hydrate.



These reactions indicate merely certain steps in the processes. An intermediate step may involve the precipitation of basic ferric sulphate.

The several hydrated iron oxides are:

		Ratio of Fe_2O_3 to H_2O .
Turgite.....	$2\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$	2 to 1
Goethite.....	$\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$	2 to 2
Limonite.....	$2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$	2 to 3
Xanthosiderite.....	$\text{Fe}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$	2 to 4
Limnite.....	$\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$	2 to 6

Ferric hydrate, $\text{Fe}(\text{OH})_3$, corresponds to limnite, but through processes of drying or with scant supplies of water the oxides which

are less highly hydrated will form. Thus limonite forms from limnite and turgite forms when limonite is dehydrated. Turgite, which contains some combined water, but less than limonite, is probably more common in gossans than is generally supposed. The hydrated iron oxides are probably not deposited by ascending hot waters except near the orifices of hot springs.

Hematite is a constituent of igneous rocks, of pegmatites, of contact-metamorphic deposits, and of veins of the deep zone. It is rarely formed by hot ascending waters at shallow or even at moderate depths. The specular anhydrous variety (specularite) is not a common secondary mineral, yet it may be formed under the conditions that prevail in dry, hot countries. Ransome¹ has described minute crystals of secondary hematite in outcrops at Goldfield, Nev. At the Modoc mine, Morenci, Ariz.,² it is formed by the surface oxidation of magnetite and garnet. In tropical countries some residual iron ores and gossans carry abundant hematite. Although hematite is the principal oxide in deposits like those of the Lake Superior iron ranges, which have been formed by the weathering of iron oxides, carbonates, and silicates,³ it is noteworthy that limonite greatly predominates in the gossans of most sulphide ores, at least in those that have formed in a temperate climate.

Magnetite, Fe_3O_4 , is a common constituent of igneous rocks and of magmatic segregations.⁴ It is present in some pegmatites, in most contact-metamorphic deposits, in vein deposits of the deeper zones, and in some ore bodies that are transitional in character between the deposits of the deep zone and those formed at moderate depth. It very rarely fills fissures in ore bodies formed at moderate depth, but at some places it occurs in greatly altered wall rock near such filled fissures. Where the alteration is less intense, usually at some distance from the ore, small dots of magnetite are said to form as a result of alteration of the ferromagnesian minerals by the spent ascending ore-depositing thermal solutions. Where it is primary, magnetite may be a residual mineral in the oxidized zone of any deposit. Minute dark magnetite particles, few if any of them showing crystal form, are found also in the outcrops of many deposits formed at moderate depth, in which the primary ore appears to be free from magnetite. Their minute size and possibly their lack of crystal form will usually serve to distinguish these particles from particles of primary magnetite.

¹ Ransome, F. L., The geology and ore deposits of Goldfield, Nev.: Prof. Paper U. S. Geol. Survey No. 66, 1909, p. 124.

² Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 103.

³ Van Hise, C. R., and Leith, C. K., The geology of the Lake Superior region: Mon. U. S. Geol. Survey, vol. 52, 1911, p. 188.

⁴ Hastings, J. B., Association of magnetite with sulphides in mineral deposits: Min. and Sci. Press, vol. 97, Sept. 5, 1908, pp. 333, 358.

The extent to which magnetite may form in the outcrop of a sulphide ore body is a matter of considerable importance in connection with the prospecting of gossans, and it has been suggested that it forms in considerable quantities near the surface as a result of certain peculiar climatic conditions.¹ Many outcrops of magnetite have been regarded as the cappings of sulphide ore bodies and have been followed downward in the hope of finding sulphide ores of gold, silver, or copper. At most places it has been found that massive magnetite is of primary origin and is persistent in depth. If rock-making minerals or the heavy silicates, such as garnet, actinolite, chlorite, and dark mica, are intergrown with the masses of magnetite, it may safely be regarded as a primary deposit and not a product of oxidation.

Melanterite, jarosite, and other sulphates and basic sulphates form abundantly in the oxidized zones of some sulphide ores. The sulphates are highly soluble and are therefore unstable. In some mines they are conspicuously developed, however, on mine timbers and on the faces of ore and wall rock. Weed states that ferrous sulphate is carried by moisture of the air circulating in mine workings.² Jarosite and other basic sulphates are much less soluble than the sulphates and persist in some lodes even at the outcrops. The basic sulphates, as already stated, are probably formed as intermediate products in the hydrolyzation of ferric sulphate to form ferric hydroxide. The abundance of limonite in the gossans indicates that the basic sulphates ultimately lose the sulphate radicle to form hydroxides. By these processes, doubtless, the downward migration of some of the sulphuric acid is delayed and sulphuric acid is contributed to the solutions that percolate through the oxidized ore even after the sulphides have been removed.

Siderite and ankerite.—Siderite is rare as a constituent of contact-metamorphic deposits, but it is found in several veins of the deep zone and also in the gangue or in the altered wall rock of deposits formed at moderate depths by hot ascending water. High temperatures are not necessary for its genesis, however, for it is most abundant in cherty iron carbonate ores of sedimentary origin. In lode ores siderite is in the main primary. Noteworthy examples are the silver-lead veins of the Wood River³ and Cœur d'Alene⁴ districts,

¹ Graton, L. C., The occurrence of copper in Shasta County, Cal.: Bull. U. S. Geol. Survey No. 430, 1910, p. 106.

² Weed, W. H., Geology and ore deposits of the Butte district, Montana: Prof. Paper U. S. Geol. Survey No. 74, 1912, p. 99.

³ Lindgren, Waldemar, The gold and silver veins of Silver City, De Lamar, and other mining districts in Idaho: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1899, p. 190.

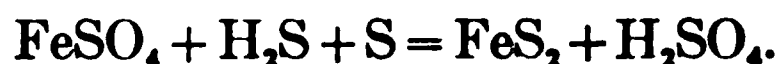
⁴ Ransome, F. L., and Calkins, F. C., The geology and ore deposits of the Cœur d'Alene district, Idaho: Prof. Paper U. S. Geol. Survey No. 62, 1908, pp. 95-97.

Idaho. It is found less abundantly also in altered wall rock at Tonopah, Nev.,¹ at Breckenridge, Colo.,² and in many other districts.

As a secondary mineral siderite is not abundant. Ferrous carbonate dissolves readily in acids³ and it could not form in a highly acid environment. At greater depths, where the environment is alkaline or basic, ferrous carbonate could be precipitated. Siderite is present in fractures in ore of the Highland Boy mine, Bingham, Utah,⁴ and according to Ransome ferrous carbonate is deposited in veinlets crossing the sulphide ore of Breckenridge.⁵ In some of the occurrences ferrous carbonate has been precipitated as ankerite, a salt that also contains, in isomorphous combination, lime carbonate, manganese carbonate, or magnesium carbonate. These salts are somewhat soluble in acid, but none are highly soluble in water.

Pyrite is formed under varying conditions of temperature and from solutions of varied character. It is one of the group termed by Lindgren "persistent" minerals. It is much more abundant, however, in ores associated with igneous processes than in deposits formed by cold solutions or in secondary deposits, although it is not unknown in the latter. Pyrite is contained in some coal beds and is common in sedimentary rocks remote from igneous intrusives. Iron sulphide is not deposited in highly acid waters and is probably not a common or abundant secondary sulphide, but it may be deposited in slightly acid or in neutral solutions. At the surface and above ground water pyrite oxidizes to basic sulphates and to limonite, but it alters in the presence of oxygen more slowly than marcasite or pyrrhotite. In some deposits it persists to the very surface, and, unoxidized, it is found in placer deposits, especially in northern, recently glaciated areas,⁶ though its occurrence in placers is not limited to these areas, for it is found in auriferous gravels in California,⁷ Colorado, and other Western States.

Pyrite as well as marcasite may be obtained by the action of hydrogen sulphide on ferric sulphate solution. Hydrogen sulphide reduces ferric sulphate to ferrous sulphate, with the separation of sulphur, and further action of hydrogen sulphide on ferrous sulphate slowly gives FeS_2 . The reaction is—



¹ Spurr, J. E., *Geology of the Tonopah mining district, Nevada*: Prof. Paper U. S. Geol. Survey No. 42, 1905, p. 248.

² Ransome, F. L., *Geology and ore deposits of the Breckenridge district, Colorado*: Prof. Paper U. S. Geol. Survey No. 75, 1911, p. 87.

³ Ostwald, Wilhelm, *The principles of inorganic chemistry* (trans. by Alex. Findlay), London, 1904, p. 580.

⁴ Boutwell, J. M., *Economic geology of the Bingham mining district, Utah*: Prof. Paper U. S. Geol. Survey, No. 38, p. 116.

⁵ Ransome, F. L., *op. cit.*, p. 169.

⁶ Brooks, A. H., *A reconnaissance of the Cape Nome and adjacent gold fields of Seward Peninsula, Alaska, in 1900*: Special publication U. S. Geol. Survey, 1901.

⁷ Becker, G. F., *Some features of the Rand Banket*: *Econ. Geology*, vol. 4, 1909, p. 379.

This reaction goes on, even at ordinary temperatures, in solutions that contain less than 1 per cent of free sulphuric acid. In solutions of greater acidity and at lower temperatures marcasite will form.¹ Examples of secondary pyrite are rare, but some have been reported.

According to Spurr, Garrey, and Ball,² pyrite is secondary in the Georgetown region, Colorado, where it has probably been deposited by descending surface waters. Hintze states that pyrite is pseudomorphous after silver glance at Joachimsthal. Veinlets of pyrite cut pyrrhotite copper ore at Ducktown, Tenn., and appear to have been deposited by descending waters. At De Lamar, Idaho, secondary pyrite is associated with kaolin.³ In view of the widespread distribution of iron, however, it is remarkable that so few occurrences of secondary pyrite have been reported from the sulphide deposits in the western United States.

Marcasite is rare as a primary mineral of igneous rocks, of pegmatites, of contact-metamorphic deposits, and of veins of the deep zones. It is rarely formed at moderate depths by hot ascending waters but has been formed near the surface or at the orifices of hot springs. It is abundant in the lead and zinc deposits of the Mississippi Valley, where it appears to have been formed by cold solutions near the surface. As pointed out by Allen,⁴ it is to be regarded as a low-temperature mineral deposited in acid solutions. In some pyritic veins it has formed as a secondary sulphide. It may be formed artificially by treating ferric sulphate with hydrogen sulphide. If the solution contains as much as 1 per cent of free sulphuric acid and the temperature is not above 100°, the product is all marcasite. At higher temperatures or in more feebly acid solutions pyrite will form.

At Ducktown, Tenn., marcasite is found sparingly in cracks associated with manganese dioxide about 200 feet below the chalcocite zone. At Goldfield, Nev., according to Ransome,⁵ marcasite is rather characteristic of soft, crushed ore and of gouge and appears in many places to be of later origin than most of the other sulphides. It is a constituent of most of the high-grade ore and in much of it is as old as gold, goldfieldite, etc. It occurs as concentric, radially fibrous shells in soft, dark, and probably enriched ore streaks. As a rule these shells disintegrate on exposure to the air, with the formation of yellow films, apparently containing a little free sulphur, a brown fibrous efflorescence of iron sulphate. It is also a fairly

¹ Allen, E. T., *Sulphides of iron and their genesis*: Min. and Sol. Press, vol. 103, 1911, p. 414.

² Spurr, J. E., Garrey, G. H., and Ball, S. H., *Economic geology of the Georgetown quadrangle, Colorado*: Prof. Paper U. S. Geol. Survey No. 63, 1908, p. 144.

³ Lindgren, Waldemar, *The gold and silver veins of Silver City, De Lamar, and other mining districts in Idaho*: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, p. 124.

⁴ Allen, E. T., *op. cit.*, p. 413.

⁵ Ransome, F. L., *The geology and ore deposits of Goldfield, Nev.*: Prof. Paper U. S. Geol. Survey No. 66, 1909, p. 115.

abundant constituent of the rich primary ore, associated with gold, pyrite, goldfieldite, alunite, quartz, etc.

Pyrrhotite, so far as is indicated by its geologic relations, is distinctly a high-temperature mineral. This conclusion is supported also by the recent synthetical work done by Allen, Crenshaw, Johnston, and Larsen,¹ who found that pyrrhotite is formed by the decomposition of pyrite in hydrogen sulphide at high temperatures. Pyrrhotite is a primary constituent of igneous rocks² and commonly occurs in magmatic segregations³ in pegmatite veins in contact-metamorphic deposits and in veins formed in the deeper zones. A number of its occurrences are mentioned on page 93. Winslow⁴ mentions the occurrence of pyrrhotite in the disseminated lead ores of southeastern Missouri, but Buckley⁵ does not list it with the ore minerals of this district. As a secondary sulphide in lode ores it is unknown.

Arsenopyrite, FeAsS , is a constituent of many pegmatite veins and has been noted as a contact-metamorphic mineral. It is a primary mineral in deposits of the deep zone and in some lodes formed at moderate depths. In such deposits it commonly carries gold. It is not known as a secondary constituent of ores enriched by descending sulphate solutions.

Chalcopyrite and *bornite* are discussed on pages 110-111.

SOME GANGUE MINERALS.

NATURE AND GENESIS.

Among the minerals found in metalliferous sulphide ores are many that are formed by processes of surface alteration only. These include a large number of the native metals, carbonates, silicates, oxides, and some other compounds. Among the sulphides not one is known to be formed exclusively by secondary processes, although several are secondary in nearly all their known deposits. On the other hand, the primary ores include several sulphides that are almost unknown as secondary minerals. A list of such sulphides should include arsenopyrite, bismuthinite, enargite?, molybdenite, pyrrhotite, and probably others.

The data concerning the genesis of many minerals are inconclusive, and to determine the origin of an ore one must generally rely on paragenesis and mineral association rather than on the occurrence of isolated species. So far as they may serve as an indication of the

¹ Allen, E. T., Sulphides of iron and their genesis: Min. and Sci. Press, vol. 103, 1911, p. 414. Allen, E. T., Crenshaw, J. L., and Johnston, John, The mineral sulphides of iron: Am. Jour. Sci., 4th ser., vol. 33, 1912, p. 169.

² Bastin, E. S., A pyrrhotitic peridotite from Knox County, Maine: Jour. Geology, vol. 16, 1908, p. 124.

³ Coleman, A. P., The Sudbury nickel deposits: Rept. Ontario Bur. Mines, 1904.

⁴ Winslow, Arthur, The disseminated lead ores of southeastern Missouri: Bull. U. S. Geol. Survey No. 132, 1896, p. 28.

⁵ Buckley, E. R., Geology of the disseminated lead deposits of St. Francis and Washington counties, Mo.: Missouri Bur. Geology and Mines, vol. 9, pt. 1, 1909.

genesis of the ore, the gangue minerals are perhaps as important as the sulphides.

It is difficult to draw sharp distinctions between gangue and ore minerals and neither of these terms is uniformly used with the same meaning. The gangue minerals are commonly distinguished as the earthy or nonmetallic minerals associated with the metal-liferous minerals in the ore. As commonly used the term gangue does not include all minerals without metallic luster nor does it exclude all minerals that contain metals. The iron-bearing silicates are almost universally regarded as gangue minerals in deposits of metals other than iron.

In the table below the minerals listed are regarded as primary. Probably none of these are formed by processes of alteration and superficial enrichment. Most of them are nonmetallic or gangue minerals.

Some minerals which are probably not formed by processes of alteration and superficial enrichment of sulphide ores.

Acmite.	Diopside.	Rhodonite.
Actinolite.	Emery.	Rutile.
Adularia.	Garnet.	Scapolite.
Albite.	Graphite.	Sillimanite.
Allanite.	Hornblende.	Spinel.
Amphiboles.	Humites.	Tourmaline.
Anhydrite.	Ilmenite.	Tremolite.
Augite.	Ilvaite.	Vesuvianite.
Biotite.	Lepidolite.	Wollastonite.
Chromite.	Microcline.	Zircon.
Corundum.	Orthoclase.	Zoisite.
Cryolite.	Pyroxenes.	

A number of gangue minerals are formed by processes of weathering and hydrometamorphism. Many of them are alteration products or replacements of older gangue minerals, but some are reprecipitated in open fissures. The term hydrometamorphism is used to define those changes which take place through the agency of surface waters at depths somewhat below the oxidizing zones—possibly at horizons where the waters have become neutral or alkaline. Several silicates are developed by such processes, among them chlorite, epidote, muscovite, quartz, serpentine, and talc. Of these minerals all except serpentine and talc are formed also, under some conditions, by ascending thermal waters.

SOME ALUMINUM MINERALS.

Occurrence.—Aluminum is abundant in the economy of nature and is a constituent of many rock-making minerals. It enters into the composition of several vein-forming minerals. Among these are the

feldspars, sericite, alunite, kaolin, diaspore, gibbsite, and bauxite. The chemical composition of some of these minerals is shown below:

Sericite.....	$K_2O.3Al_2O_3.6SiO_2.2H_2O.$
Alunite.....	$K_2O.3Al_2O_3.4SO_3.6H_2O.$
Kaolin	$Al_2O_3.2SiO_2.2H_2O.$
Diaspore.....	$Al_2O_3.H_2O.$
Gibbsite.....	$Al_2O_3.3H_2O.$
Bauxite.....	$Al_2O_3.2H_2O.$

Although new mineral combinations result from hydrothermal processes, there is little evidence that much aluminum is carried into the veins by ascending hot solutions, for aluminum compounds are rare indeed in veins contained in nonaluminous rocks. Cold acid sulphate solutions dissolve aluminum from its compounds very readily, as is indicated by many of the analyses of mine waters (pp. 60–63). There is but little evidence, however, that aluminum compounds are extensively precipitated in open spaces from cold acid waters. Some alunitic veinlets are secondary and some kaolin is deposited in fractures by descending solutions, but in most deposits the larger proportion of the secondary aluminous gangue appears to be a residual product of altered feldspar, sericite, and other minerals. Without much doubt aluminum, like iron, is carried out of sulphide ore bodies in great quantities, for the slimes precipitated from mine waters commonly contain large proportions of hydrous aluminum compounds.

Feldspars.—Of the feldspars, albite and adularia are primary gangue minerals of ore veins. Albite is generally formed at considerable depth; adularia nearer the surface. Neither feldspar is known to form in cold solutions by processes of secondary alteration, although adularia, according to Lindgren,¹ may be deposited at or near the surface where the temperature could not have been much above 100° C.

Sericite.—Of the vein minerals that carry aluminum, sericite is perhaps the most common. It is formed in the main as a pseudomorphous replacement of feldspar or other aluminous silicates. In some replacement veins it is very abundant and was probably formed by ascending thermal waters, although there is much evidence that it forms also by processes of hydrometamorphism² that are independent of processes of ore deposition. Hickling³ states that sericite is an intermediate product of the kaolinization of potash feldspar exposed to atmospheric weathering. There is little evidence, however, that

¹ Lindgren, Waldemar, Metasomatic processes in fissure veins, in Pošepný, Franz, The genesis of ore deposits, 1902, p. 532.

² Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 125.

³ Hickling, George, China clay; its waters and origin: Trans. Inst. Min. Eng. [London], vol. 36, 1903-4,

sericite forms extensively under the conditions that prevail where secondary sulphides are deposited.

Kaolin, $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$, is a common product of rock alteration under surface conditions. It forms where aluminum silicates are leached by ground water that contains either carbonic or sulphuric acid. It is abundantly present in the oxidized zone and in the zone of enrichment in nearly all sulphide ore deposits. As a primary vein constituent¹ it is exceedingly rare. At Goldfield, Nev., according to Ransome,² it was probably deposited simultaneously with alunite and gold by ascending thermal waters. In several other districts, as at the Rosita Hills, Colo., and Rabbit Hole, Nev., it is associated with alunite and commonly with diasporite or other hydrous aluminum oxides. Rösler³ regards kaolin as a pneumatolytic product. According to Gregory,⁴ the deposits of kaolin or china clay of Cornwall and Devon extend to the bottom of some deep mines and probably to greater depths. These he regards as having been formed by solutions containing boric and fluoric acids. Hickling,⁵ however, regards the kaolin of Cornwall as entirely secondary. At Goldfield, Nev., kaolin was formed very near the surface by ascending hot waters and probably by partly oxidized sulphate waters. Nearly all these data appear to show that kaolin is indicative of acid waters.

It has been shown that precipitation of copper sulphide may liberate sulphuric acid, which is available for kaolinization of sericite or feldspar or other aluminum minerals, and consequently kaolin is commonly an associate of secondary chalcocite and covellite in aluminous rocks. At Butte, Mont., according to S. F. Emmons,⁶ kaolin associated with secondary copper sulphides was found 1,100 feet deep in the East Gray Rock mine, and Kirk⁷ also has reported it at great depths. It is abundantly developed in the oxidized ores at Bisbee, Ariz.,⁸ and probably also with chalcocite ores. It is not uncommon as a secondary product at Morenci, Ariz.,⁹ where, according

¹ Lindgren, Waldemar, The relation of ore deposition to physical conditions: Econ. Geology, vol. 2, 1907, p. 120. Ransome, F. L., Criteria of downward sulphide enrichment: Econ. Geology, vol. 5, 1910 p. 212; discussion by S. F. Emmons, p. 477.

² Ransome, F. L., The geology and ore deposits of Goldfield, Nev.: Prof. Paper U. S. Geol. Survey No. 66, 1909, p. 192.

³ Rösler, H., Beiträge zur Kenntnis einiger Kaolinlagerstätten: Neues Jahrbuch, Beil.-Bd. 15, 1902, p. 231; Ueber Kaolinbildung: Zeitschr. prakt. Geologie, 1908, p. 251.

⁴ Gregory, J. W., Criteria of downward sulphide enrichment (discussion): Econ. Geology, vol. 5, 1910, p. 680.

⁵ Hickling, George, China clay; its waters and origin: Trans. Inst. Min. Eng. [London], vol. 36, 1908-9, p. 24.

⁶ Emmons, S. F., The secondary enrichment of ore deposits, in Pošepný, Franz, The genesis of ore deposits, 1902, p. 443.

⁷ Kirk, C. T., Conditions of mineralization in the copper veins at Butte, Mont.: Econ. Geology, vol. 7, 1912, p. 35.

⁸ Ransome, F. L., The geology and ore deposits of Bisbee, Ariz.: Prof. Paper U. S. Geol. Survey No. 21 pp. 32, 147.

⁹ Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1906, p. 111.

to Lindgren, it is not formed during the sericitization of the porphyry which accompanied the formation of the pyritic veins, but it accompanies in small amounts the chalcocite in the veins in porphyry and the copper carbonates in decomposed deposits in limestone. It occurs as veinlets in the quartz of several mines and as large masses in the Longfellow mine, where it is adjoined by limonite. Pure white kaolin commonly occurs also with azurite. According to Lindgren,¹ its formation in limestone may be explained by the action of aluminum sulphate on free silica in the presence of cupric sulphate:



At Georgetown, Colo., according to Spurr, Garrey, and Ball, kaolin is crystallized in vugs.

Kaolinic ores commonly carry high values in gold and silver. A noteworthy example is seen at the Montgomery Shoshone mine of the Bullfrog district, Nevada, where the richer ores were found in altered claylike rhyolite. At many places rich kaolinic secondary ores of silver are extensively developed—for example, in the Broken Hill lode, Australia.²

Alunite, $\text{K}_2\text{O} \cdot 3\text{Al}_2\text{O}_3 \cdot 4\text{SO}_3 \cdot 6\text{H}_2\text{O}$, is a white or faintly pink mineral which in some of its occurrences closely resembles kaolin and sericite. It is formed from either hot or cold solutions. It is not known to have formed under high temperature and great pressure. The alunitic deposits of Goldfield, Rabbit Hole, and Alunite, Nev., and of the Rosita Hills and Rico, Colo., have been formed presumably by hot ascending waters mixed with oxygenated surface waters. The alunitic veinlets at Cripple Creek, Colo.,³ and at Clifton-Morenci, Ariz.,⁴ and the "Chinese talc" of Leadville, Colo., have probably been deposited by descending cold sulphate waters. Alunite is commonly associated with kaolin and the ranges of the two minerals are probably closely similar. Alunite is much less soluble than some other sulphates of aluminum and is therefore relatively stable in oxygenated solutions. The occurrence and genesis of alunite have recently been discussed by Butler and Gale.⁵

Gibbsite, bauxite, and diaspore.—Gibbsite, $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$, bauxite, $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$, and diaspore, $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$, are hydrated aluminum oxides corresponding to the hydrous iron oxide series. By extreme weathering, especially in moist, hot climates, these minerals are formed

¹ Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 193.

² Clark, Donald, Australian mining and metallurgy, 1904, p. 347.

³ Lindgren, Waldemar, and Ransome, F. L., Geology and gold deposits of the Cripple Creek district, Colorado: Prof. Paper U. S. Geol. Survey No. 54, 1906, p. 125.

⁴ Lindgren, Waldemar, op. cit., p. 119.

⁵ Butler, B. S., and Gale, H. S., Alunite, a newly discovered deposit near Marysvale, Utah: Bull. U. S. Geol. Survey No. 511, 1912.

from aluminum silicates.¹ They have been reported from comparatively few ore veins and those in which they have been identified are almost without exception of late Tertiary age. It is believed that they have been formed in some deposits very near the surface by reactions upon aluminum silicates.² The waters were oxidized solutions, probably hot sulphate waters. In the altered rhyolite of the Rosita Hills, Colo.,³ diaspore is associated with alunite, quartz, and kaolin, and in altered latite near Silverton, Colo.,⁴ with alunite and kaolin. Microscopic crystals of diaspore have been identified at several places in the alunitic-kaolinic veins of Goldfield, Nev.⁵

SILICA.

It is generally assumed that ascending hot waters are alkaline solutions. If they were acid at their sources they would become alkaline by reactions with wall rocks composed mainly of alkaline silicates.⁶ Although the alkalies are generally regarded as its natural solvents, silica is dissolved also by acid waters. The amount, though small, is appreciable even in solutions that give strongly acid reactions, and each of the 37 samples of water whose analyses are stated on pages 60–63 carries silica. In dilute acid waters the silica is generally assumed to be mainly or altogether in the colloidal state. It would be supposed that silica would increase with carbon dioxide, but this is not clearly apparent from a survey of the analyses, nor is the increase of alkalies with silica pronounced. The water that is richest in silica is a strongly acid water of the Comstock lode (No. 23).

The secondary metallic silicates chrysocolla, calamine, and willemite have already been discussed. These are formed possibly in the presence of acid solutions, and to judge from their mineral association, the various forms of hydrated silica, such as chalcedony and chert, may be formed under similar conditions. It is doubtful whether clear crystalline quartz is deposited to any considerable extent by cold descending acid sulphate waters. In the zinc deposits of southwest Wisconsin, which were formed presumably by cold sulphate waters, quartz is notably absent. Some of the disseminated lead ores of southeastern Missouri carry 5 per cent silica, and an appreciable amount of silica is present in the sulphate-

¹ Worth, H. and F. J., *Geol. Mag.*, 1903, p. 154. Worth, H., *Min. Mag.*, vol. 13, p. 172, 1902.

² Hayes, C. W., *Geology of the bauxite region of Georgia and Alabama: Sixteenth Ann. Rept. U. S. Geol. Survey*, pt. 3, 1895, p. 547; *Trans. Am. Inst. Min. Eng.*, vol. 24, 1904, p. 243.

³ Cross, Whitman, *Geology of Silver Cliff and the Rosita Hills, Colo.: Seventeenth Ann. Rept. U. S. Geol. Survey*, pt. 2, 1896, pp. 316–317.

⁴ Ransome, F. L., *Economic geology of the Silverton quadrangle, Colo.: Bull. U. S. Geol. Survey No. 182*, 1901 (reprinted in 1903), pp. 121–124.

⁵ Ransome, F. L., *Geology and ore deposits of Goldfield, Nev.: Prof. Paper U. S. Geol. Survey No. 66*, 1909, p. 125.

⁶ Allen, E. T., *Sulphides of iron and their genesis: Min. and Sci. Press*, vol. 108, 1911, p. 413.

carbonate waters of the mines of that region. The mine waters¹ carry considerable quantities of alkalies and alkali earths and give an alkaline reaction. Certain quartzose ore deposits have been regarded as the results of enrichment or concentration by downward-moving waters, and clear crystalline quartz is found in geodes remote from igneous intrusives and forms the interstitial filling of sandstones that have been converted into quartzites.

The association of sulphide ores with abundant quartz is commonly supposed to indicate that they were deposited by alkaline solutions. A study of the paragenesis of most deposits yields results that are in harmony with this conclusion, for quartz, as above stated, is deposited sparingly with secondary sulphide ores. In some deposits, however, it occurs as veinlets filling small cavities and is clearly more recent than the bulk of the ore. Some such veinlets may be due to deposition from descending solutions. At Tintic, Utah, evidence of deposition of quartz in late stages of ore formation is very clear.² At Lake City, Colo., according to Irving and Bancroft³—

the white quartz occurs without question in more than one generation, but the bulk of it is younger than any of the metallic minerals, for it cuts through sphalerite, galena, tetrahedrite, pyrite, and even rhodochrosite in places. Veinlets of this white quartz also frequently cement shattered masses of the metallic minerals.

At Cripple Creek⁴ quartz replaces celestite, but the period of its genesis is presumably uncertain. As emphasized by Van Hise,⁵ the quartz deposited by descending waters is laid down mainly below the zone of weathering in the "belt of cementation." Lindgren places it in the group with epidote, muscovite, pyrite, and other minerals that are formed distinctly below the zone of active oxidation. The valuable contribution of Wright and Larsen⁶ on the use of quartz as a geologic thermometer should be mentioned here, since it suggests methods that may lead to a more definite understanding of the genesis of quartzose deposits.

Chalcedony, chert, jasper, and like minerals are cryptocrystalline forms of silica which are deposited under different conditions of temperature and pressure. They are more abundant in deposits formed by sedimentary processes, in cold-water deposits, in secondary zones, in sinters, and in veins of late geologic age than in veins formed at depths under higher temperature and pressure. In the latter crystalline quartz is more common.

¹ Buckley, E. R., *Geology of the disseminated lead deposits of St. Francois and Washington counties, Mo.*: Missouri Bur. Geology and Mines, vol. 9, pt. 1, 1909, p. 249.

² Tower, G. W., and Smith, G. O., *Geology and mining industry of the Tintic district, Utah*: Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1899, p. 692.

³ Irving, J. D., and Bancroft, Howland, *Geology and ore deposits near Lake City, Colo.*: Bull. U. S. Geol. Survey No. 478, 1911, p. 60.

⁴ Lindgren, Waldemar, and Ransome, F. L., *Geology and gold deposits of the Cripple Creek district, Colorado*: Prof. Paper U. S. Geol. Survey No. 54, 1906, p. 123.

⁵ Van Hise, C. R., *A treatise on metamorphism*: Mon. U. S. Geol. Survey, vol. 47, 1904, pp. 634-636.

⁶ Wright, F. E., and Larsen, E. S., *Quartz as a geologic thermometer*: Am. Jour. Sci., 4th ser., vol. 28, 1909, p. 421.

The secondary chalcedonic quartz that is commonly associated with sulphide ores should be especially noted here. At Cananea, Sonora; Morenci, Ariz.; Goldfield, Nev.; and near Silverton, Colo. (Yankee Girl and similar deposits), many of the ore deposits are capped with highly siliceous outcrops, whereas the ore at short distances below the surface is not so siliceous. A concentration of silica at the surface in some of these deposits is unmistakable, yet in several of them not all the silica appears to be residual quartz of the ore accumulated at the surface by the removal of other minerals. Some shallow pits at Cananea pass through a siliceous capping into white material, streaked with iron oxide, consisting principally of sericite and kaolin with small crystals of pyrite and chalcopryrite and probably of some residual feldspar. This loose cellular material contains very little silica, and as its pore spaces carry crystals of iron and copper sulphates it is a natural inference that sulphate solutions have attacked the kaolin and by long-continued action have removed aluminum and set silica free. Analyses of mine waters indicate that some acid solutions dissolve aluminum in considerable quantities, for it is present in appreciable amount in nearly all the waters and was noted in four samples from Cananea.

Kaolin is generally regarded as a comparatively stable mineral in the oxidized zone. At Morenci, Ariz., however, according to Lindgren,¹ kaolin is decomposed by acids, which carry aluminum into solution. Such reactions may be attended by the liberation of silica, which presumably would be hydrous silica, but at the very surface, perhaps, the hydrous varieties are dehydrated to form quartz, after the manner that limonite is dehydrated in hot dry climates to form hematite.

Siliceous cappings are extensively developed in and near the copper-bearing porphyry at Ely, Nev. Lawson² has shown, however, that some of the siliceous material or "blout" that outcrops at Ely is probably residual jasper.

SULPHUR AND SULPHATES.

SOLUBILITY.

The genesis of the principal sulphates of copper, lead, zinc, iron, and aluminum has already been considered. In all their occurrences these minerals are probably secondary, except alunite, the sulphate of aluminum and potash, which is primary in some deposits. Several of the sulphates—for example, those of magnesium, manganese, zinc, and silver—are so soluble that they rarely accumulate in ore

¹ Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1906, p. 193.

² Lawson, A. C., The copper deposits of the Robinson mining district, Nevada: Bull. Dept. Geology Univ. California, vol. 4, 1906, p. 327.

deposits and are of little or no importance as vein minerals. The solubilities of some of the sulphates (determined by Kohlrausch) are stated below.

K_2SO_4	Na_2SO_4	Ag_2SO_4	$BaSO_4$	$SrSO_4$	$CaSO_4$	$MgSO_4$	$ZnSO_4$	$PbSO_4$
111.1 .62	168.3 1.15	5.5 .02	0.0023 .00001	0.11 .0006	2.0 .015	354.3 2.8	531.2 3.1	0.041 .00013

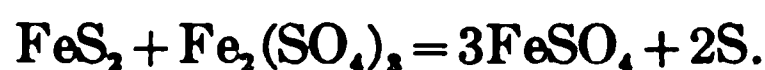
The upper number shows the number of grams in a solution of 1 liter of water; the lower number the molar solubility.

Of the sulphates that occur as gangue minerals, gypsum, barite, and celestite are important. Anhydrite¹ is much less common, although it is abundant as a gangue mineral in some deposits of the Newhouse district, Utah. Under oxidizing conditions it is unstable and passes into the hydrated calcium sulphate, gypsum.

OCURRENCE.

Native sulphur is not an abundant alteration product of sulphide ores. The sulphur of commerce is obtained from other sources. Small quantities of sulphur, however, are not rare in oxidized or partly oxidized ores. As shown by Vogt, it is formed from several sulphides by reaction with ferric chloride. According to Spurr, sulphur has formed on the outside of sulphide ore on the dump of the Leadville mine at Aspen.² It incrusts sulphide ores in the Bunker Hill mine at Henderson, Mont., and occurs sparingly in the altered ores of Ducktown, Tenn. It is an alteration product of galena in the Mountain View lead mine of Carroll County, Md.,³ and in the Wheatley mine near Phoenixville, Pa.⁴ With anglesite it coats cavities in galena at Tintic, Utah.⁵

According to Stokes,⁶ sulphur is formed in the first stage of the oxidation of pyrite. The reaction is—



The sulphur readily reacts with ferric sulphate to give more ferrous sulphate and acid:



In the presence of ferrous sulphate and hydrogen sulphide, sulphur unites with ferrous sulphide⁷ to form pyrite and with silver⁸ to form

¹ Lindgren, Waldemar, *Anhydrite as a gangue mineral*: Econ. Geology, vol. 5, 1910, p. 525.

² Spurr, J. E., *Geology of the Aspen mining district, Colorado*: Mon. U. S. Geol. Survey, vol. 31, 1898, p. 239.

³ Williams, G. H., *Zeitschr. Krystallographie und Mineralogie*, vol. 22, 1894, p. 575.

⁴ Hintze, Carl, *Handbuch der Mineralogie*, vol. 1, 1897, p. 90.

⁵ Tower, G. W., Jr., and Smith, G. O., *Geology and mining industry of the Tintic district, Utah*: Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1899, p. 704.

⁶ Stokes, H. N., *On pyrite and marcasite*: Bull. U. S. Geol. Survey No. 186, 1901, p. 15.

⁷ Allen, E. T., Crenshaw, J. L., and Johnston, John, *The mineral sulphides of iron*: Am. Jour. Sci., 4th ser., vol. 33, 1912, p. 169.

⁸ Cooke, H. C., unpublished manuscript.

argentite. By these and other processes it is probably removed from most deposits nearly as rapidly as it is formed.

Gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, is a common mineral of ore veins but is rare in portions of deposits that have not been exposed to oxidizing solutions. According to A. E. H. Tutton,¹ gypsum is decomposed at 150°C ., and possibly at 120° . It has probably been formed invariably at low temperatures. Gypsum is present in decomposed vein matter at Cripple Creek² and at Creede, Colo., and in the secondary sulphide zone at Butte, Mont.³ Veinlets of gypsum are abundant at Ely, Nev., in ores in porphyry. At Morenci, Ariz., according to Lindgren,⁴ it is present in oxidized deposits in limestone, where copper carbonates are formed by reaction between sulphates and calcium carbonates. It forms from calcite at Aspen, Colo.,⁵ and is in part postglacial, for it cements glacial débris. It is associated with the altered ores at Tonopah, Nev.,⁶ and is present in most of the deposits of Goldfield, Nev.,⁷ where it occurs below the zone of oxidation. In the Dixon mine, Bingham, Utah, according to Boutwell,⁸ a considerable body of gypsum was found between the carbonate lead-silver ore and the parent sulphides. Crystals of gypsum are coated with hematite in the Ajax mine at Tintic, Utah.⁹

Barite, BaSO_4 , has not been identified in igneous rocks,¹⁰ in pegmatites, or in contact-metamorphic deposits but is found in both the oxidized and unoxidized portions of ore lodes. It is not unknown in some deposits presumably formed at considerable depths. In the Gold Hunter mine of the Cœur d'Alene district¹¹ it is associated with galena, sphalerite, and tetrahedrite. In this district it is present also in the ore of the Standard-Mammoth mine. In some of the sulphide copper ores of Shasta County, Cal.,¹² barite is a characteristic gangue mineral. In many deposits of later age, which were presumably formed nearer the surface, barite is abundant. It is present in many

¹ Tutton, A. E. H., The optical constants of gypsum at different temperatures: Proc. Royal Soc. London, vol. 81A, 1908, p. 40.

² Lindgren, Waldemar, and Ransome, F. L., Geology and ore deposits of the Cripple Creek district, Colorado: Prof. Paper U. S. Geol. Survey No. 54, 1906, p. 125.

³ Winchell, A. N., Criteria of downward sulphide enrichment (discussion): Econ. Geology, vol. 5, 1910, p. 489.

⁴ Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 120.

⁵ Spurr, J. E., Geology of the Aspen mining district, Colorado: Mon. U. S. Geol. Survey, vol. 31, 1898, p. 24.

⁶ Spurr, J. E., Geology of the Tonopah mining district, Nevada: Prof. Paper U. S. Geol. Survey No. 42, 1905, p. 96.

⁷ Ransome, F. L., The geology and ore deposits of Goldfield, Nev.: Prof. Paper U. S. Geol. Survey No. 66, 1909, p. 128.

⁸ Boutwell, J. M., Economic geology of the Bingham mining district, Utah: Prof. Paper U. S. Geol. Survey No. 38, 1905, pp. 119, 204.

⁹ Tower, G. W., jr., and Smith, G. O., Geology and mining industry of the Tintic district, Utah: Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1899, p. 694.

¹⁰ Clarke, F. W., The data of geochemistry, 2d ed.: Bull. U. S. Geol. Survey No. 491, 1911, p. 555.

¹¹ Ransome, F. L., and Calkins, F. C., The geology and ore deposits of the Cœur d'Alene district, Idaho: Prof. Paper U. S. Geol. Survey No. 62, 1908, p. 103.

¹² Gratton, L. C., The occurrence of copper in Shasta County, Cal.: Bull. U. S. Geol. Survey No. 430, 1910, p. 102.

lode deposits of southwestern Colorado, in some of which, as noted by Irving and Bancroft,¹ it was formed by ascending hot waters. In some veins that are of great vertical extent barite is abundant in their higher portions but lacking at greater depths. It is inferred that the barite is primary but was deposited under lower pressures than those which prevailed in the deeper parts of the veins. In many Lake City deposits it is the most abundant mineral. It is clearly of earlier deposition than quartz, for quartz very commonly incrusts crystals that project into central cavities.

The deposits at Creede, Colo.,² contain considerable barite. Some of this is thought to have formed as a primary constituent of the ore, but some that fills cracks and crevices in limonite is later than the first period of mineralization and is probably secondary. At Wagon-wheel Gap, near by, it has formed along a fissure near which hot springs now issue. At Aspen, Colo., barite is cut by veinlets of argentite and native silver and is intimately associated with polybasite.³ It is found with kaolinite in deposits at Goldfield, Nev.⁴ Barite is commonly present in the gangue of copper deposits in the "Red Beds" of the Southwest that have formed through the agency of cold solutions.⁵

Although barite forms under conditions of surface alteration, it is not so commonly associated with the secondary sulphides as gypsum and kaolin. Owing to its insolubility it persists in the oxidized zones. In many deposits it outcrops at the surface and it is found in oxidized ores from which all the sulphides have been dissolved.

Celestite, SrSO_4 , is not reported as an original constituent of igneous rocks, of pegmatites, or of contact-metamorphic deposits.* It occurs in certain ore bodies that were formed relatively near the surface by hot ascending waters. It is formed also in deposits far removed from igneous rocks, and in some lodes it is probably a secondary mineral deposited by cold sulphate waters. It is not nearly so common as barite.

Although celestite is relatively rare in ore veins, at Cripple Creek it is both a primary and secondary mineral. Slender needles of celestite coat openings in the vein fissures far below the zones of oxidation⁶ and pseudomorphs of quartz after celestite are of frequent occurrence in some of the Cripple Creek deposits.

¹ Irving, J. D., and Bancroft, Howland, Geology and ore deposits near Lake City, Colo.: Bull. U. S. Geol. Survey No. 478, 1911, pp. 34, 35, 45.

² Emmons, W. H., and Larsen, E. S., Geology and ore deposits of Creede, Colo.: Bull. U. S. Geol. Survey (in preparation).

³ Spurr, J. E., Geology of the Aspen mining district, Colorado: Mon. U. S. Geol. Survey, vol. 31, 1898, p. 228.

⁴ Ransome, F. L., The geology and ore deposits of Goldfield, Nev.: Prof. Paper U. S. Geol. Survey No. 66, 1909, p. 128.

⁵ Lindgren, Waldemar, Graton, L. C. and Gordon, C. H., The ore deposits of New Mexico: Prof. Paper U. S. Geol. Survey No. 68, 1910, p. 78.

⁶ Lindgren, Waldemar, and Ransome, F. L., Geology and gold deposits of the Cripple Creek district, Colorado: Prof. Paper U. S. Geol. Survey No. 54, 1906, p. 126.

Jarosite, $K_2O \cdot 3Fe_2O_3 \cdot 4SO_4 \cdot 6H_2O$, is a brownish-yellow sulphate that resembles limonite in color and occurrence and is easily confused with that mineral. Like limonite it forms in the oxidized zone of iron sulphide deposits. It occurs at Tintic, Utah, and probably at Goldfield, Nev.¹ It is found at the outcrop of the Amethyst vein at Creede, Colo. Mr. B. S. Butler informs me that it is present in the oxidized ore in a number of deposits in Utah.

CARBONATES.

The alkali-earth carbonates are fairly insoluble in water, as indicated in the following table:

Solubility of some carbonates in water at 18°.

K_2CO_3	Na_2CO_3	Ag_2CO_3	$BaCO_3$	$SrCO_3$	$CaCO_3$	$MgCO_3$	$ZnCO_3$	$PbCO_3$
1080 5.9	193.9 1.8	0.03 .0001	0.023 .00011	0.011 .00007	0.013 .00013	1.0 .01	0.04? .0003?	0.001 .00003

The upper number gives the grams of anhydrous salt held in solution by 1 liter of water; the lower number the molar solubility or number of mols contained in a liter of the saturated solution. The determinations were made by Kohlrausch by the conductivity method.

In sulphide ores barium carbonate (witherite) and strontium carbonate (strontionite) are rare. Calcite and dolomite are more common as vein minerals. In accordance with their occurrence in deposits formed under widely different conditions both are termed persistent minerals.² Both are attacked by sulphuric acid, and calcite is dissolved in very dilute acid sulphate solutions. It could not be formed, therefore, in moderately acid waters. Where secondary in sulphide deposits, both calcite and dolomite are formed mainly below the zone of active oxidation, in solutions that have become feebly acid or alkaline.

The occurrence of the carbonates of copper, lead, and zinc has already been discussed. These are formed from acid solutions and are deposited extensively in oxidized zones. None of them are known to form in depth by deposition from thermal waters. Siderite (ferrous carbonate) is less common in lode deposits and is generally primary. It is deposited, however, under some conditions of sedimentation—for example, in the “black band” iron ores. Its occurrence as a product of surface alteration is exceedingly rare,

¹ Ransome, F. L., The geology and ore deposits of Goldfield, Nev.: Prof. Paper U. S. Geol. Survey No. 66, 1909, p. 133.

² Lindgren, Waldemar, The relation of ore deposition to physical conditions: Econ. Geology, vol. 2, 1907, p. 108.

although the ferrous-carbonate molecule is present in ankerite and in some other carbonates which are assumed to be secondary in some deposits. According to Ransome,¹ impure siderite occurs in veinlets traversing sulphide ores at Breckenridge, Colo.

Rhodochrosite, the carbonate of manganese, is fairly abundant in many precious-metal ores. In the United States it is almost unknown in such deposits that are older than the Tertiary. There is little evidence that rhodochrosite is deposited by descending sulphate waters, although the manganese-carbonate molecule is probably present in some complex carbonates that are assumed to be secondary. In the bog-manganese deposits, which have formed by sedimentary processes, the manganese oxides predominate, but some of these deposits contain also rhodochrosite.² Although the soluble carbonates precipitate silver carbonate from solutions of silver salts in the laboratory, and although silver sulphate is more soluble than silver carbonate, the latter is nevertheless unknown in mineral deposits.

SUMMARY REVIEW OF SEVERAL CLASSES OF DEPOSITS.

On the following pages a number of the principal sulphide deposits of copper, gold, and silver ores in North America are briefly described, in order that the several districts may readily be compared to ascertain the extent, character, and distribution of the secondary ores in them. As already stated, many of the problems arising in this connection are now only in process of solution. Yet by grouping these deposits in several ways, certain facts are more or less clearly indicated. The conclusions stated below appear to be warranted by the data presented herewith.

COPPER DEPOSITS IN GENERAL.

1. The deposits of many copper districts do not exhibit evidence of appreciable chalcocite enrichment. Examples: Kasaan Peninsula, Alaska; Prince William Sound, Alaska; Sudbury, Ontario; Boundary district, British Columbia; Copperopolis, Cal.; Frisco, Utah (Cactus mine); La Reforma mine, Mexico; probably San Jose, Velardeña, and Nacozari, Mexico. The mines of the Braden Copper Co., operating in Chile, may be added to this list.

2. Deposits showing no chalcocite enrichment, located in countries that have recently been glaciated, include those of the following regions: Kasaan Peninsula and Prince William Sound, Alaska; Sudbury, Ontario; Boundary district, British Columbia. They include also deposits in countries that, so far as I can discover, have not

¹ Ransome, F. L., *Geology and ore deposits of the Breckenridge district, Colorado*: Prof. Paper U. S. Geol. Survey No. 75, 1911, p. 169.

² Penrose, R. A. F., jr., *The superficial alteration of ore deposits*: Jour. Geology, vol. 2, 1894, p. 306.

recently been glaciated: La Reforma, Copperopolis?, Nacozari, San Jose.

3. Deposits that do not contain appreciable chalcocite zones are found in countries of widely different latitudes: Alaska, British Columbia, Ontario, California, Utah, Mexico, and Chile.

4. Deposits that do not contain appreciable chalcocite zones exhibit primary ores containing pyrrhotite: Kasaan Peninsula and Prince William Sound, Alaska; Sudbury, Ontario; Boundary district, British Columbia. They also exhibit primary ores, in the available descriptions of which pyrrhotite is not mentioned: La Reforma; Copperopolis; Cactus mine, Utah; Nacozari (some bornite enrichment), San Jose, Velardeña, Mexico; Braden, Chile.

5. All or nearly all the pyrrhotitic deposits which do not exhibit secondary chalcocite zones are in recently glaciated areas. Some of these deposits carry sphalerite.

6. All the deposits described that are located in the lower latitudes and that show no appreciable chalcocite enrichment have primary ores of pyrite and chalcopyrite. Zinc blende is wanting or not abundant in most of these deposits, but Velardeña (Copper Queen mine) and Frisco (Cactus mine) are exceptions. Possibly there are some others. In none of these deposits is pyrrhotite reported.

7. In glaciated areas oxidized ores for this group are subordinate or lacking. In areas not glaciated a few of the deposits exhibit oxidized ores of some commercial importance.

8. In all or nearly all the deposits in low latitudes which do not show appreciable chalcocite enrichment complete oxidation has proceeded to comparatively shallow depths. The lodes in general are said to be relatively impervious. The copper-sulphate solutions probably move laterally and issue at the surface before reducing conditions are met, or, escaping into the wall rock, their copper content is scattered. La Reforma is a good example.

9. I know of no pyrrhotitic copper deposit in a low latitude or in a country not glaciated that shows no chalcocitization whatever. Some pyrrhotite at least reacts so readily with acid to give hydrogen sulphide that acid solutions may be reduced and copper sulphide may be precipitated even with access of some air. Precipitation of a copper sulphide is now in progress on ore surfaces in mines of Ducktown, Tenn., above the present water level. Such precipitation probably does not take place in the higher levels on pyrite and chalcopyrite.

10. The copper content of some of the pyrrhotitic deposits in glaciated areas decreases with increase in depth. Possibly a former chalcocite zone was planed off by the ice and a secondary chalcopyrite zone was not completely removed. This is strongly suggested by relations in the Boundary district, British Columbia.

COPPER DEPOSITS WITH SHALLOW CHALCOCITE ZONES.

11. Many copper deposits exhibit shallow chalcocite zones. These include Ducktown, Tenn.; Stone Hill, Ala.; Gossan lead, Va.; Ely, Vt.; Queen of Bronze mine, Oreg.; Santiago, Cuba; Pinar del Rio, Cuba; and La Dicha, Mexico. Possibly Encampment, Wyo.; Shasta County, Cal.; and the Highland Boy mine of Bingham, Utah, should be mentioned here.

12. The examples cited above are outside of the limits of the continental ice sheets. A deposit on Prince William Sound, Alaska, however, shows a few inches of secondary sulphide ore.

13. The ores of all but one of these deposits carry pyrrhotite. In most of them it is abundant. The ores of Shasta County, Cal., carry considerable sphalerite but little or no pyrrhotite.

14. The chalcocite zones of most of the deposits of this group range in vertical dimensions from 1 foot to 10 feet. In some of the deposits, however, their vertical extent is 200 feet or more.

15. The secondary chalcocite ores of these deposits are generally rich. Some of them carry over 20 per cent copper.

16. Gold or gold and silver are very commonly concentrated in the secondary copper ores.

17. A zone of chalcopyrite enrichment may exist below the chalcocite zone, and it may be of considerably greater vertical extent than the secondary chalcocite zone. Examples: Ducktown, Tenn.; Rio Tinto, Spain; possibly others.

18. Pay ores are commonly found below the zone of probable chalcopyrite enrichment and some of them are of moderately high grade. Few, if any, however, could be classed as bonanza.

COPPER DEPOSITS WITH MODERATELY DEEP CHALCOCITE ZONES.

19. In many deposits of copper-sulphide ores secondary chalcocite extends to moderately great depths. Examples are Morenci, Bisbee, Globe, Miami, Ray, and Jerome, Ariz.; Santa Rita (Chino), N. Mex.; Ely, Nev.; Bingham, Utah (in part); Cananea, Sonora (in part); Butte, Mont. In many of these deposits the vertical extent of the chalcocite zone is from 200 to 1,000 feet or more.

20. These deposits are outside of the margins of the continental ice sheets.

21. Many of these deposits are in countries now arid.

22. Pyrrhotite is subordinate in the ores of all these deposits.

23. The primary ores of several of these districts carry appreciable sphalerite. Examples are Morenci, Metcalf, Jerome?, Cananea (West Cobre Grande and Kirk). At Morenci and Metcalf the bulk

of the chalcocite is within 400 feet of the surface. In the West Cobre Grande chalcocite passes into low-grade zincky ores about 200 feet below the surface. Exact data are not available for Jerome and for certain Bingham mines.

24. The deepest secondary chalcocite zones are in ore bodies that contain little or no pyrrhotite or sphalerite. Examples: Bisbee, Globe, and Miami, Ariz.; Bingham laccolith, Utah; Butte, Mont. (in part). A few deposits of this character have chalcocite zones that probably are not of much greater vertical extent than chalcocite zones in some sphalerite deposits. Examples are Ray, Ariz., and possibly Santa Rita (Chino), N. Mex.

25. Sphaleritic ores do not appear to check the downward migration of copper so readily as they check the downward migration of silver. (See below.)

26. Important zones of chalcopyrite enrichment below the chalcocite zones have not been clearly differentiated in any of these deposits.

COPPER DEPOSITS WITH DEEPLY OXIDIZED ZONES.

27. Copper deposits having deeply oxidized zones include many of those of Tintic, Utah, and Bisbee, Ariz.; some of Bingham, Utah; and the Snowstorm mine of the Cœur d'Alene district, Idaho.

28. None of these deposits are known to carry pyrrhotite or abundant sphalerite.

29. The data here presented indicate that in general oxidized zones above ores containing abundant pyrrhotite and sphalerite are more thoroughly oxidized than those above ores containing pyrite and chalcopyrite without pyrrhotite or sphalerite, but such oxidation is not likely to extend to depths so great in pyrrhotite or sphalerite ores. The pyrite ores of Rio Tinto, Spain, those of La Reforma mine, Mexico, and some of the deposits at Butte, Mont., are capped by thoroughly oxidized material; possibly there are others.

30. The deepest zones of oxidized copper ores are in deposits in limestone. Examples: Tintic, Utah, and Bisbee, Ariz.

31. Although oxidation extends 2,000 feet below the surface at Tintic, and perhaps 1,600 feet or more at Bisbee, it is, in general, not complete at such depths.

32. Not all the deeply oxidized zones of copper ores are in arid countries (Snowstorm mine, for example).

33. The nature and vertical extent of chalcocite enrichment and the depth of oxidation depend upon the permeability of the deposits, the chemical and mineral composition of the ores and wall rock, the present and the past climatic environment, and the geologic history.

GOLD DEPOSITS EXHIBITING SECONDARY CONCENTRATION.

34. Many auriferous deposits in the surficial zone appear not to have been enriched by secondary agencies. The distribution of valuable deposits in the lodes of Berners Bay and Douglas Island, Alaska, shows no relation to the present surface. In this glaciated region there is little or no concentration of gold at the surface by removal of valueless material from the outcrops.

35. There is no evidence of solution and reprecipitation of gold in some other auriferous deposits in lower latitudes, although there may be an increase of values at the outcrop through oxidation that is attended by the removal of material with which the gold is associated. Examples are Mother Lode, Nevada City, Grass Valley, Ophir, and similar deposits of California; Homestake deposits of the Black Hills; Cable mine, between Philipsburg and Anaconda, Mont.; and several deposits in the Appalachians. Practically all the important deposits in these regions have supplied placer gold.

36. There are still other deposits whose relations do not indicate a migration of gold and from which no placers have been exploited. Examples: Edgemont, Nev.; Goldfield, Nev.; Silver Peak, Nev.; Cripple Creek, Colo. (subordinate placers). Not all of these are in arid regions, Edgemont and Cripple Creek being moderately well watered.

37. Solution, migration, and reprecipitation are clearly indicated in a number of auriferous deposits. In some of them this is inferred from paragenetic evidence, in others from the great richness of the bonanzas compared with the unaltered ore and from the relations of the bonanzas to the present surface. Examples are found at Creede, Colo. (Amethyst vein); Ouray, Colo. (Camp Bird vein); Telluride, Colo. (Tomboy vein); some veins in quartzite near Leadville, Colo.; Little Burro Mountains, N. Mex. (Wyman vein); Bodie, Cal.; Bullfrog, Nev.; Manhattan, Nev.; Gold Circle, Nev.; Mohave, Cal. (Exposed Treasure vein); Georgetown, Colo. (auriferous lodes?); Marysville, Mont. (Drumlummon veins). All the deposits named above carry manganese in greater or less amounts.

Although they are not reviewed herein, several districts outside of North America may be mentioned as examples of manganimiferous deposits with rich superficial zones. One of these is the Aroroy district, Philippine Islands. Here, according to Henry G. Ferguson, there is a difference in the behavior of gold in manganimiferous deposits and in those containing little or no manganese dioxide at the outcrop. He says:¹

As far as a limited observation extends, all veins which on their outcrops show rich ore are those in which manganese oxide is not prominent. Evidence from development work, though very meager, seems to show that the values in these veins do not

¹ Ferguson, H. G., *The gold deposits of the Philippine Islands: Econ. Geology*, vol. 6, 1911, p. 128.

increase downward, as is the case with the manganese-bearing veins, and in some at least decrease greatly a few meters from the surface. The manganese-bearing veins, on the other hand, which at their outcrop may be nearly barren, carry values increasing progressively downward. This increasing value in moderate depth is shown in many cases, but most clearly by samples taken in the 30-meter raise to surface from the upper level of the Nancy mine of the Eastern Mining Co. In this case there was an increase downward from the outcrop from less than 1 gram to over 6 grams per ton.

A conspicuous foreign example is the Mount Morgan mine in Queensland, one of the largest gold deposits in the world. The ores in depth are sulphides and carry a considerable percentage of copper but relatively little gold. To a depth of 270 feet the surface ores contained masses of enormously rich gold ore highly stained with manganese. Much of this ore carried several ounces to the ton, but copper was almost entirely absent. As pointed out by Donald Clark,¹ there is clear evidence of solution and precipitation of gold. It was not all dissolved, however, for some placer gold is found in beds of Cretaceous age near by.

The Hauraki gold fields, New Zealand, may be mentioned also. The vein filling is massive or comby quartz, with some manganese dioxide. According to A. M. Finlayson,² some of the small ore shoots are exceedingly rich. The bonanza zone extends 400 to 600 feet below the surface.

38. Four districts are mentioned below in which gold has migrated in solution in ores that are not stated to carry manganese. Two of these (Haile mine, South Carolina, and Hedley district, British Columbia) are in regions of basic rocks, which possibly supply manganese to the solutions. Two others (Bohemia district, Oregon, and Summit district, Colorado) are in acidic and intermediate rocks. Manganese is not mentioned as a vein constituent, although its presence is not denied.

39. The outcrops of manganiferous gold ores are commonly leached, and placer deposits are not so frequently developed from them as from nonmanganiferous lodes. This is apparent from the inspection of the lists above. Two examples are conspicuous exceptions—Marysville, Mont., and Mount Morgan, West Australia. Both have enormously rich deposits, practically at the surface; both have supplied placer gold. The unaltered ores of one (Marysville) carry calcite, which reduces auriferous solutions very rapidly. Some rich manganiferous gold ores are found very near the surface at Bullfrog and Manhattan, Nev. At both places the gangue is calcitic.

40. It is concluded that the solution of gold depends in the main on the presence, simultaneously, of manganese and chlorides. Its migration depends on the permeability of the lodes and the material

¹ Clark, Donald, *Australian mining and metallurgy*, Melbourne, 1904, p. 267.

² Finlayson, A. M., *Problems in the geology of the Hauraki gold fields, New Zealand: Econ. Geology*, vol. 4, 1909, p. 641.

of the primary ores. Of the common minerals, calcite and pyrrhotite will probably reduce auriferous solutions most rapidly. Some other carbonates and sphalerite are doubtless somewhat less efficient. The action with pyrite and chalcopyrite is slower still.

SILVER AND SILVER-GOLD DEPOSITS.

41. Enrichment is clearly indicated in a number of silver and silver-gold deposits. Examples may be found at Georgetown, Breckenridge, Leadville, Aspen, Silverton, Creede, and Lake City, Colo.; at Philipsburg, Butte, and Neihart, Mont.; on the Comstock lode, at Tonopah, and at Pioche, Nev.; at Mohave, Cal.; and in the St. Eugene mine, at Moyie Lake, British Columbia. In several of these districts, but not in all, a migration of gold also is clearly indicated. All the districts of silver-gold deposits in which gold is assumed to have migrated include manganiferous ores.

42. In deposits carrying both metals, especially where chlorides form, secondary silver minerals are likely to be precipitated as bonanzas near the surface, while gold may be carried to greater depths. Examples are deposits of Mohave, Cal. (Exposed Treasure mine), Creede, Colo. (Amethyst lode), and probably the Comstock lode, Nevada, although in the Comstock district silver chloride is not abundant.

43. In manganiferous deposits of gold and silver where chlorides do not form extensively, silver is probably carried downward to greater depths than gold. Clearly defined examples are rare, perhaps because gold is not dissolved in cold mineral waters free from chlorine and because silver chloride is so nearly insoluble that precipitation of cerargyrite is almost certain to take place in the ores where chlorides are supplied by the ground waters, even in small amounts. Although some examples seem to indicate that silver migrates downward below the zone where gold is precipitated, the data are generally inconclusive.

44. Abundant pyrrhotite in the primary ore quickly halts the downward migration of both silver and gold. Some of the secondary ore of the "black copper floors" of Ducktown, Tenn., carried considerable silver. A sample assay by Genth showed over 1 per cent. Not many examples are available, probably because the pyrrhotitic ores carry copper and the rich superficial concentrations were worked out before the days of electrolytic refining. Since acid waters generate hydrogen sulphide on at least some pyrrhotite almost immediately, and since hydrogen sulphide precipitates gold and silver perhaps completely, the gold and silver could not descend to any considerable depth in pyrrhotitic ores. Although the principal ore deposits of Rio Tinto, Spain, carry little or no pyrrhotite and although zinc blende is not abundant in most of them, they should be mentioned here. Above

one of the principal deposits there is a "floor" of rich silver and gold ore at or just above the top of the chalcocite zone.¹

45. In general, without much doubt, in copper deposits where silver and gold migrate downward it is in the upper part of the zone of secondary copper sulphides that the precious metals are precipitated rather than in the lower part.

46. Many deposits of rich silver ore and some deposits of rich silver-gold ore terminate downward in low-grade sphalerite ores. Abundant examples are to be found in the regions of Georgetown, Breckenridge, Creede, and Lake City, Colo.; Pioche, Nev.; and Lake Moyie, British Columbia. In most of these districts the bonanzas of silver ores are comparatively near the surface. In the Comstock lode and at Tonopah, Nev., and in the Granite-Bimetallic vein at Philipsburg, Mont., a little zinc is present, but not much. In these the richer ores are found at greater depths. At Creede, Colo., in the Amethyst vein, secondary silver ore has been formed at greater depths than is usual in the region of Georgetown and Breckenridge, notwithstanding the fairly abundant zinc sulphide in the primary ore at Creede. This, I believe, is to be explained by excessive fracturing of the Amethyst vein, which at some places is little more than an ore breccia, and by the fact that soluble carbonates are almost lacking in the ore.

A conspicuous example outside of America of a deposit of rich silver-lead ore passing into low-grade sphalerite ore in depth is the great Broken Hill lode of New South Wales. This deposit is in schists and in general conforms to the schistosity. Judging from the drawings of Capt. Warren² it resembles in certain structural features the broken folds of some of the deposits of Ducktown, Tenn. Though classed as a saddle reef by J. B. Jaquet³ on account of its bifurcating structure, it may be considered, for the purpose of this discussion, a tabular mass, since the bifurcation of the lode is shown between the 415 and 515 foot levels, from which point it extends to the surface as a tabular body. Without much doubt a considerable amount of the lode has been eroded, and the valuable metals appear to have concentrated in the remaining portion relatively near the surface. Siliceous limonitic manganitic ore is said to have extended from the surface to about 300 feet below. This ore was 20 to 100 feet wide and, according to Phillips and Louis,⁴ carried 7 to 45 ounces silver and 18 per cent lead. At the bottom of this siliceous ore was a narrow zone of kaolinic ore, portions of which carried great bonanzas of silver, largely in the form of chloride. Below this level, on block 10, at a depth

¹ Vogt, J. H. L., *Das Huelva-Kiesfeld*: *Zeitschr. prakt. Geologie*, 1899, p. 250. Finlayson, A. M., *The pyritic deposits of Huelva, Spain*: *Econ. Geology*, vol. 5, 1910, p. 410.

² *Reminiscences of Broken Hill*, quoted by Clark, Donald, *Australian mining and metallurgy*, Melbourne, 1904. The original is not accessible to me.

³ Jaquet, J. B., *Geology of the Broken Hill lode and Barrier Ranges mineral field, New South Wales*. Mem. Geol. Survey New South Wales, Geology No. 5, 1894.

⁴ Phillips, J. A., *A treatise on ore deposits*, 2d ed., by Henry Louis, 1896, p. 655.

between 400 and 500 feet below the surface, were rich friable sulphides with galena and zinc blende.¹ Below the rich friable sulphides values decreased greatly, the ore being composed of "compact sulphides, or an intimately mixed mass of galena and blende, with a gangue of quartz, rhodonite, and garnet." I have no record that pyrrhotite is present in these ores, though it is mentioned as abundant in the Pinnacles mine, 9 miles southwest of Broken Hill.²

47. Auriferous and argentiferous acid solutions are probably more sensitive than cupriferous solutions to the presence of sphalerite, because ferrous sulphate will precipitate gold and silver from chloride and sulphate waters, whereas copper sulphate will remain in solution with ferrous sulphate. Hydrogen sulphide, which may be generated by acid and sphalerite, will precipitate all three of the metals, but hydrogen sulphide is used up to convert ferric to ferrous sulphate. Thus copper may remain in solution as long as any ferric sulphate is present, but gold and silver would go down in mixtures of ferric and ferrous sulphates. Under similar conditions in sphaleritic ore copper would descend to greater depths than gold and silver.

48. Although the chemical and mineralogic environment in depth have been emphasized in the foregoing discussion, it is recognized that permeability of the primary ores is a factor of the greatest importance in determining the depths to which the metals may descend, whatever the character of the primary sulphides.

REVIEW OF MINING DISTRICTS.

BUTTE, MONTANA.

The Butte district,³ in western Montana, is an area of quartz monzonite (the Butte quartz monzonite, frequently called granite) which is intruded by a later aplite, or aplitic granite (in early reports sometimes alluded to as the "Bluebird granite"), and by rhyolite porphyry (in early reports called quartz porphyry).

Dikes of late Tertiary rhyolite cut the granite, and effusive rhyolite (rhyolite dacite) rests upon it. In the western part of the region are Tertiary lake beds more recent than the granitic rocks. These are composed of sand, gravel, and water-laid tuff. The rhyolite porphyry has in some reports been referred to as the "Modoc porphyry," and it is locally known by that name. In the most recent publica-

¹ Phillips, J. A., A treatise on ore deposits, 2d ed., by Henry Louis, 1896, p. 347.

² Idem, p. 657.

³ Weed, W. H., Emmons, S. F., and Tower, G. W., jr., Butte folio (No. 38), Geol. Atlas U. S., U. S. Geol. Survey, 1897. Weed, W. H., Geology and ore deposits of the Butte district, Montana: Prof. Paper U. S. Geol. Survey No. 74, 1912. Winchell, H. V., Synthesis of chalcocite and its genesis at Butte, Mont.: Eng. and Min. Jour., vol. 75, 1903, pp. 782-784. Sales, Reno, Ore shoots at Butte, Mont.: Econ. Geology, vol. 3, 1908, pp. 326-331; Superficial alteration of the Butte veins: Idem, vol. 5, 1910, pp. 15-21. Simpson, J. F., The relation of copper to pyrite in the lean copper ores of Butte, Mont.: Econ. Geology, vol. 3, 1908, pp. 628-636. Kirk, C. T., Conditions of mineralization in the copper veins at Butte, Mont.: Econ. Geology, vol. 7, 1912, pp. 35-82.

tion on this area¹ it is called rhyolite porphyry. Its groundmass is microcrystalline, however, and, as Weed very truly states, it might be classed as granite porphyry.

The quartz monzonite, aplite, and porphyry, which contain all the ores, are phases of the great Boulder batholith, which extends some 64 miles southward from a point near Helena and is 12 to 16 miles wide. This batholith intrudes Paleozoic and Cretaceous sedimentary rocks and along its borders has induced contact metamorphism by which the typical garnet zones have been developed in the calcareous sediments.

Although the rocks of the batholith are in general of comparatively uniform composition, the Butte quartz monzonite is a somewhat more basic phase. The aplite represents a differentiation product that was forced into cracks in the quartz monzonite after that rock had cooled. Although there is an unusual amount of the aplite in the region about Butte, its economic significance is not clear. Indeed, the lodes, on passing from the quartz monzonite into aplite, are impoverished, and Weed² states that the aplite is uncongenial for ore deposition because it fractures with difficulty and is not readily replaced.

There seems to be a genetic relationship between the copper ores and the rhyolite porphyry, although such a relation is not conclusively proved. The rhyolite porphyry is found only in the eastern portion of the copper area, where it is younger than the Butte quartz monzonite and older than the veins, since even the oldest veins cut through it. The veins in the porphyry, like those in the aplite, are narrower and poorer than those in the quartz monzonite. The porphyry is, however, the youngest igneous rock exposed that is older than the oldest veins.

The copper ores are included in an area about 1½ miles long and a mile wide, and this area is almost surrounded by a much larger area containing closely spaced silver-bearing veins. Pronounced parallelism is noticeable in veins of both groups.

The region is highly fractured and extensively faulted; indeed, faulting movements have continued probably to the present day. In a general way the fractures, as stated by Weed, may be separated into two classes; the first, formed before the rhyolitic eruptions (Miocene), trend either (a) east and west or (b) northwest and southeast; the second, accompanying or following the rhyolite intrusions, trend in the same directions as the first, but are most marked in a (c) northwest or (d) northeast direction. Still later, after ore deposition, northeast fracturing occurred.

The earliest fracturing recognized is that which is assumed to have taken place in the partly consolidated mass of Butte quartz monzo-

¹ Weed, W. H., *op. cit.*, p. 41.

² *Idem*, p. 96.

nite, causing openings which were filled by the analogous but more acidic magma that cooled as aplite.

The rhyolite porphyry intrusion, which probably took place after both the Butte quartz monzonite and the aplite had been consolidated, formed irregular dike-like bodies which have a general northwest trend, though the one in the Anaconda mine runs east and west.

The most important fracturing—that which formed the fissures that admitted the earliest mineral-bearing solutions—occurred subsequent to both aplite and rhyolite porphyry intrusions.

Subsequent to the original deposition of minerals along the vein fissures several dynamic movements took place, each producing fracturing which affected the mineral deposits. These later movements have formed cross fissures faulting the earlier veins and strike fissures coincident with or parallel to and reopening earlier veins. Important mineralization has taken place also along cross fissures.

The volcanic outbreak which caused the rhyolite intrusion occurred subsequent to the earlier vein fissuring, as is shown by the fact that the silver veins are cut off, in places even cut in two, by the intrusive dikes of rhyolite. The relation of these rhyolite dikes to the different periods of late fracturing is, however, not positively known. More than one postmineral movement took place, for the rhyolite dikes have been markedly sheeted and somewhat fractured since their intrusion. The rhyolite intrusion itself, however, was probably accompanied by a certain amount of fracturing of the adjoining rocks. It is therefore not improbable that the secondary fracturing, which had an important bearing on the enrichment of the copper veins, was genetically connected with the intrusion of the rhyolite.¹

The ores are of two distinct classes, copper and siliceous silver. The copper ores contain a little silver; the silver ores rarely contain copper; both copper and silver ores contain a little gold, and the high-grade silver ores contain it in important amounts.²

Chalcocite, enargite, and bornite are the most common copper minerals. Covellite occurs in large amounts in one mine and in small amounts in others. Chalcopyrite is present in workable quantities in a few properties but is an insignificant part of the total copper output. Tetrahedrite is found as a rarity in the deep workings of a few mines. Chalcanthite, or native bluestone, is common in the old workings. Pyrite is the most common sulphide. It is estimated that since the beginning of mining about 75 per cent of the copper production has come from glance, 20 per cent from enargite, 4 per cent from bornite, 0.5 per cent from covellite, and 0.5 per cent from chalcopyrite.

¹ Weed, W. H., *op. cit.*, pp. 58-59.

² *Idem*, p. 65.

Silver occurs native in the copper ores, especially in those from the upper levels. Ruby silver and indeterminable black sulphantimonites and arsenides occur in the siliceous silver ores. Free gold is rare but occurs in some silver ores and has been seen in specimens from the Leonard mine, where it is parasitic on glance.¹ The gangue minerals include quartz, sericite, and several residual minerals of the altered country rock. Rhodonite and rhodochrosite occur in silver ores.

The mountains near by have been glaciated in recent geologic time, but no morainal material is found in the immediate vicinity of Butte.²

The average precipitation is less than 20 inches, but the loose disintegrated material near the surface favors extensive seepage of rain water. The few records of "first water" for the older mines appear to locate it at about the upper limit of the sulphide ores. This upper limit varies greatly, ranging from about 20 feet to 400 feet, being in part independent of the surface level but varying with the degree of fracture.

In the quartz monzonite the network of lesser fractures and the veins and faults are apparently all filled with water and serve as a vast reservoir. That this water has a natural level not far below that of the neighboring valleys is evident, and that it is moving slowly downward can not be doubted, though it can not be readily proved. The conditions of mineralization afford some evidence of this; and in the East Ridge region, where higher collecting ground exists, the springs became dry when the Altona mine was pumped out to a depth of some 200 feet, proving a connection between the mine waters and surface drainage. The drying out of the upper workings of some of the mines when the surface seepage is eliminated shows that in these mines the waters come from above. In short, all the evidence shows that the waters are surface waters seeping downward. They come, however, from a broad area, and not from the surface of the Butte mines alone.³

In opening new ground the amount of water, as stated by Weed, seems to be proportionate to the block of ground opened—that is, the ground between the new level and the old workings above. In a few places rising water was encountered at the deep levels—for instance, on the 2,200-foot level of the Mountain Con. mine and on the 1,600-foot crosscut of the Anaconda (where uprising waters were encountered some 2,000 feet from other workings)—but the outflow diminished in a few weeks and finally all but ceased, indicating that the area from which the water came was probably drained.⁴

The oldest deposits are the east-west lodes, of which the Parrot, Anaconda, and Syndicate are examples. These occupy fissures along

¹ Weed, W. H., *op. cit.*, p. 72.

² *Idem*, p. 30.

³ *Idem*, p. 98.

⁴ *Idem*, p. 97.

which there was but slight tangential movement.¹ The ore minerals in these veins consist chiefly of pyrite, chalcopyrite, chalcocite, covellite, etc. Pyrrhotite is not mentioned in the descriptions of these or any later deposits. I am informed by Mr. Reno Sales that sphalerite is widespread and abundant in the copper veins except in that part of the district extending from the Neversweat mine eastward through the Anaconda, St. Lawrence, Mountain View, Pennsylvania, Leonard, and Silver Bow mines. In these properties it is almost entirely absent, both in these and later vein systems. Westward, in the Steward, Original, and Gagnon² mines, sphalerite is abundant, as it is in the Colorado, Clear Grit, Buffalo, and Paulin mines and also in many of the silver lodes.

A later set of veins strikes northwest across the east-west veins. These contain, in addition to the minerals named as constituents of the earlier veins, large quantities of enargite. Along these veins evidence of movement parallel to the planes of the deposit is more pronounced. Although mineralization of the earlier veins is comparatively uniform, the later veins are characterized by barren patches separating rich ore shoots. These ore shoots, as shown by Sales,³ are of primary origin, the course of the mineralizing solutions having been determined by fault gouge which effectively dammed back the waters from the portions of the fissures that are barren.

A still later set of fissures, having a northeast course, has displaced both earlier sets. This system, according to Weed,⁴ contains little endogenous ore, but the material mined is mainly fault breccia from earlier deposits. In many of the veins later movement is pronounced.

The depth of oxidation of the copper deposits is treated briefly on page 37. The leached zone extends downward in places 300 or 400 feet below the surface. It contains some silver but little copper. Below the oxidized zones enormous masses of chalcocite, with some bornite and covellite, were encountered.

In the great ore bodies of the upper levels of the Anaconda veins chalcocite occurred, according to Weed,⁵ in masses of nearly pure leadlike mineral 20 feet or more wide. In depth the mineral shows a more crystalline structure, and it is found in all the mines in greater or less abundance and purity, but in the great bulk of the ores it forms small grains scattered through the ores.

Emmons, Weed, Tower, and many others who studied the copper lodes in the earlier stages of their development regarded the chalcocite ores as secondary deposits formed by descending waters. Weed⁶

¹ Sales, Reno, Ore shoots at Butte, Mont.: *Econ. Geology*, vol. 3, 1908, p. 327.

² Pearce, Richard, The association of minerals in the Gagnon vein, Butte City, Mont.: *Trans. Am. Inst. Min. Eng.*, vol. 16, 1888, pp. 62-64.

³ Sales, Reno, *op cit.*, p. 326.

⁴ Weed, W. H., *The copper mines of the world*, New York, 1907, p. 326.

⁵ *Idem*, p. 327.

⁶ *Idem*, p. 328.

says, "As a general statement it may be said that the deposits of copper glance are secondary."

C. T. Kirk,¹ after a comprehensive study of the ores of the Pitts-mont mine of this district, concluded that the chalcocite was secondary, basing his argument in part on its association with kaolin.

As a result of microscopic studies of polished surfaces of ores, John F. Simpson² concluded that the copper sulphides were deposited in the following order: Chalcopyrite, enargite, bornite, chalcocite. Pyrite from the 2,000-foot level of the Mountain Con. mine is cut by veinlets of bornite and contains flakes of chalcocite. In ore from the 800-foot level of the Alex Scott mine chalcocite surrounds pyrite, enargite, and chalcopyrite and occurs as veins in the pyrite.

As the underground workings have been carried deeper, and as chalcocite ores have been developed in depth, doubt has been expressed more and more as to the validity of the conclusion that the chalcocite ores are wholly secondary. Graton³ in 1906 called attention to the fact that on the whole the copper veins in depth are dry. Sales⁴ in 1910 advanced the opinion that the chalcocite in the lower levels of the lodes is primary. Mr. H. V. Winchell informs me that he has reached the same conclusion. Weed⁵ mentions a fine body of chalcocite ore on the 2,400-foot level of the Anaconda group, and later developments, according to Sales, have exposed chalcocite 2,800 feet deep. One of the photomicrographs from a deep level figured by Simpson shows pyrite inclosing small chalcocite masses in relations that are hard to reconcile with the conclusion that the chalcocite is of later age. In a collection of the School of Mines, University of Minnesota, ores from deep levels at Butte show covellite intergrown with tetrahedrite and chalcocite intergrown with pyrite, and there is no evidence that any of these minerals are replacements of older sulphides.

In Weed's most recent report on the district⁶ he states that the bulk of the ore is altered quartz monzonite containing disseminated grains and veinlets of chalcocite intergrown with pyrite or replacing that mineral completely. He also notes that chalcopyrite is but sparingly developed, constituting but 0.5 per cent of the ore mined. The copper of the secondary ore must therefore have been derived in the main from enargite, cupiferous pyrite, or older chalcocite.

¹ Kirk, C. T., Conditions of mineralization in the copper veins at Butte, Mont.: Econ. Geology, vol. 7, 1912, p. 35.

² Simpson, J. F., The relation of copper to pyrite in the lean copper ores of Butte, Mont.: Econ. Geology, vol. 3, 1908, p. 635.

³ Graton, L. C., Mineral Resources U. S. for 1906, U. S. Geol. Survey, 1907, p. 400.

⁴ Sales, Reno, Superficial alteration of the Butte veins: Econ. Geology, vol. 5, 1910, p. 15.

⁵ Weed, W. H., The copper mines of the world, New York, 1907, p. 331.

⁶ Weed, W. H., Geology and ore deposits of the Butte district, Mont.: Prof. Paper U. S. Geol. Survey No. 74, 1912, p. 76.

A drawing by Bard ¹ shows an inch vein of chalcocite cutting quartz. The chalcocite incloses idiomorphic crystals of pyrite and quartz, and both of these minerals seem to be spaced with some regularity in the chalcocite. The spacing suggests eutectic structure and the relations appear to be nearly identical with those in an ore from Mexico, described by D. P. Hynes,² where tetrahedrite incloses quartz. Although Weed believes that chalcocite is mainly secondary at Butte, he also recognizes its primary origin. He says:³

From the studies made of thin sections it is believed that the mineral is 'almost universally secondary but that it also occurs as a primary mineral in some veins. It is undoubtedly in process of formation by descending waters at the present time, but as the great ore bodies found at deep levels are far below the present level of ground water they can not have been produced by the reactions commonly offered in explanation.

It should be noted here, however, that the history of vein formation at Butte and also the recent physiographic history of the Butte district are exceedingly involved, a fact that diminishes somewhat the value of generalizations for solving the problems of ore formation.

Some of the veins have been depressed by faulting ⁴ more than 500 feet since they were formed. Evidence of descending water and of extensive solution and recent deposition is found at unusual depths. Watercourses are shown in some veins over 2,000 feet below the surface.

The physiographic history of the region has doubtless been favorable to a very deep descending circulation. In a previous paper ⁵ Weed says:

The region has passed through several very pronounced changes in elevation since the formation of the veins in Tertiary time. In early Tertiary time the present topography was blocked out and the mountain ranges and deep intervening valleys were carved. This was succeeded by earth movements by which the streams became clogged or the valleys dammed, forming lakes; while volcanoes broke out at numerous places and showered ashes and scoria over the region. The valleys were silted up or in part filled by volcanic débris, before crustal movements drained the valleys and altered the divides. More recent movement, possibly still continuing, is marked by faults and a reversing of stream courses. The old valley at Butte is filled by hundreds of feet of débris, and a mountain wall 2,500 feet high marks a north and south fault line. These changes all caused a migration of water level facilitating the processes of weathering and enrichment, and the great bodies of rich copper ores of the region are believed to be in part due to this cause.

In 1907, according to Graton,⁶ the copper ores averaged 2.75 per cent copper, 2.3 ounces silver, and 0.014 ounce gold to the ton. Few data are available on the downward migration of gold and silver in the deposits. Although manganese minerals are abundant

¹ Weed, W. H., loc. cit. The original is not available to me.

² Hynes, D. P., Notes on the geology of the Mina Mexico vein: *Econ. Geology*, vol. 7, 1912, pp. 280-286. See also this bulletin, p. 46.

³ Weed, W. H., loc. cit.

⁴ Weed, W. H., op. cit., p. 111.

⁵ Weed, W. H., The enrichment of gold and silver veins: *Trans. Am. Inst. Min. Eng.*, vol. 30, 1901, p. 448.

⁶ Graton, L. C., Mineral Resources U. S. for 1907, pt. 1, U. S. Geol. Survey, 1908, p. 610.

in the silver lodes that surround the silver-bearing area, it is said that the principal copper ores do not contain manganese,¹ and the solution of gold in them presumably has been delayed. To judge from their position, some, at least, of the gold placers that were worked in the early days at Butte were derived from the waste of the copper lodes. The valuable metal in the oxidized ore of the copper lodes was chiefly silver, the gold being of subordinate value.

BINGHAM, UTAH.

The Bingham district, Utah,² is an area of Carboniferous quartzites and limestones intruded by monzonite and monzonitic porphyry and covered in part by andesites, andesitic porphyries, and breccias. The rocks are tilted, faulted, and in places highly shattered. The ore deposits are in or near the intrusive monzonite or monzonitic porphyry. They include fissure veins in several formations, bedding-plane deposits in limestones, and disseminated deposits in shattered porphyry. The ore bodies that until recently have been most productive are large replacement deposits of sulphide ore in limestone. These ores consist chiefly of pyrite, chalcopyrite, sphalerite, and chalcocite, with a little bornite and enargite and their oxidation products. In many of the deposits a little pyrrhotite is present, and in some ore from the Highland Boy mine pyrrhotite is more abundant than pyrite and somewhat more abundant than chalcopyrite.³

In some of the mines oxidation is deep, extending to depths several hundred feet below the surface. In the Brooklyn mine⁴ oxidation is reported to a depth 1,450 feet below the surface; in the Highland Boy it is only 300 feet deep. In some of the deposits chalcocite ores extend to considerable depths and in others they are subordinate. The chalcocite zone in the Highland Boy seems not to have been extensive. Boutwell notes that the secondary oxidized ores of copper and gold pass into a zone characterized by chalcopyrite tarnished and coated with bornite and seamed with limonite. A winze sunk through oxidized ore encountered gold in considerable quantities, some of the ore running over \$30 to the ton. Five thousand tons of ore shipped early in the development of this mine are said to have averaged 12 per cent copper and \$4 gold to the ton and to have contained much silver. It is reported also that the valuable metals in each of the three principal ore bodies ran higher in the upper than in the lower levels. The ores of the lower levels carried pyrite,

¹ Pearce, Richard, The association of minerals in the Gagnon vein, Butte City, Mont.: Trans. Am. Inst. Min. Eng., vol. 16, 1888, p. 63. Emmons, S. F., Notes on the geology of Butte, Mont.: Idem, p. 55.

² Boutwell, J. M., Economic geology of the Bingham mining district, Utah: Prof. Paper U. S. Geol. Survey No. 38, 1905.

³ Idem, p. 105.

⁴ Idem, p. 215.

pyrrhotite, chalcopyrite, considerable gold, and some silver. In 1906 and 1907, according to Graton,¹ practically all the copper from these deposits was derived from the pyritic ore.

Another type of ore deposit which in recent years has become highly productive contains copper ore disseminated in the monzonite porphyry. The principal deposit of disseminated ore is in the intrusive body at Upper Bingham known as the Bingham laccolith. According to Boutwell² this extensive mass of monzonite carries disseminated throughout its areal extent, so far as known, irregular grains of pyrite and chalcopyrite. The mineralized tract contains a multitude of thin unsystematized parting planes. The rock is greatly bleached, silicified, and sericitized in and near the areas of great shattering. The copper content is lowest in the oxidized zone at the surface. Farther down, in the unoxidized rock, the copper ore lies in flat scales and films in silicified walls of cracks, and in areas of great shattering it occurs abundantly on quartz-coated cracks and is disseminated through the silicified bleached walls. The quartz, the sericite, and possibly the biotite in this ore are later than the original rock-making minerals. I can find no record of the occurrence of pyrrhotite in these ores. Zinc blende is not mentioned in Boutwell's description of this deposit, although it is abundant in some of the lode ores in the monzonite—for example, in that of the Last Chance mine.³ Although some of the metals may have been present in the rock when it solidified,⁴ the larger part of the primary sulphides was introduced by thermal waters after the porphyry had solidified.

Of the surface alteration of disseminated ores Boutwell says:⁵

Superficial alteration has followed the deposition of chalcopyrite and pyrite. Pyrite about its periphery and along cracks which traverse these planes may be seen going over to limonite. This fact * * * doubtless explains the relative enrichment of gold values proved by assays to exist in the outer or surface portions of test tunnels in these copper and gold bearing intrusives. The brilliant tarnish of grains of chalcopyrite indicates a beginning of alteration, and thin rims of a dark grayish-black metal about chalcopyrite observed under the microscope suggest continuance of that process and replacement by black copper sulphide. Rims of a blue-black metallic sulphide occur around grains of chalcopyrite. The reason for the decrease in assay values of copper along certain open and water-bearing fracture zones is doubtless to be found in the well-known fact that under the action of surface waters copper suffers rapid alteration and transportation.

It appears, then, that in the disseminated ores in igneous rock the copper minerals were deposited by hydrothermal action subsequent to the date of igneous intrusion, and that these sulphides are now undergoing normal superficial alteration.

The Utah Copper Co., which is exploiting the ores of the Bingham laccolith, is said to have developed about 300,000,000 tons, the

¹ Graton, L. C., Mineral Resources U. S. for 1906, U. S. Geol. Survey, 1907, p. 404; *idem* for 1907, pt. 1, 1908, p. 615.

² Boutwell, J. M., *op. cit.*, p. 167.

³ *Idem*, pp. 160, 178.

⁴ *Idem*, p. 171.

⁵ *Idem*, p. 172.

average content of which is about 1.5 per cent copper and from 20 to 30 cents a ton in gold and silver. The surface of this ore body occupies an area of 214 acres and the average thickness of the workable ore is probably about 418 feet.¹

The leached capping, which is stripped by steam shovels, has an average thickness of 80 feet on the Utah ground, 160 feet on the Boston Consolidated ground, and 173 feet on the Pay Roll ground, the average for the entire area being 106 feet. The mine figures indicate that the average depth of the bottom of the deposit now workable is more than 500 feet below the surface, although it extends downward in places more than 900 feet below the surface.² In much of the ore, especially in that of lower levels, chalcopryite is an important ore mineral, and considerable masses of the ore carry very little chalcocite. It is not known whether the chalcopryite is a primary or secondary sulphide.

In 1911 the Utah Copper Co. produced from copper ore about a million dollars in precious metals, four-fifths of which was gold and about one-fifth silver. This is equivalent to about \$0.225 per ton of ore and 1.07 cents per pound of copper. It is said that gold values are concentrated in the oxidized zone, but below it they tend to increase or decrease with the copper content of the sulphide ore.

BISBEE, ARIZONA.

The geology of the Bisbee (Warren) district, Arizona, was studied in detail about eight years ago by Ransome.³ Since the publication of his report the known productive area has been much extended and large new mines have been developed, especially in a part of the district to whose economic possibilities this report specifically directed attention. In view of these later developments Mr. Ransome, who revisited Bisbee in 1912, has kindly prepared the following note, in which is presented more recently acquired information than could have been included in a mere abstract of published work.

NOTE ON THE BISBEE DISTRICT, ARIZONA.

By F. L. RANSOME.

The fundamental rocks of the Bisbee district are the pre-Cambrian Pinal schist and probably also the granite mass of Juniper Flat, north of Bisbee, which is intrusive into the schist. Although the age of this granite is not directly evident from its geologic relations and although in Professional Paper 21 and in the Bisbee folio it was regarded provisionally as Mesozoic, the texture and character of

¹ Seventh Ann. Rept. Utah Copper Co., for 1911.

² See cross section, *idem*.

³ Ransome, F. L., The geology and ore deposits of the Bisbee quadrangle, Arizona: Prof. Paper U. S. Geol. Survey No. 21, 1904; Bisbee folio (No. 112), Geol. Atlas U. S., U. S. Geol. Survey, 1904.

the rock, in the light of subsequent experience in Arizona, suggest pre-Cambrian age. Resting on the schist in successive upward sequence are (1) the Bolsa quartzite (Cambrian), 430 feet thick; (2) the Abrigo limestone (Cambrian), 770 feet thick; (3) the Martin limestone (Devonian), 325 feet thick; (4) the Escabrosa limestone (Mississippian, "Lower Carboniferous"), 700 feet thick; and (5) the Naco limestone (Pennsylvanian, "Upper Carboniferous"), 3,000 feet or more thick. These beds were intruded in early Mesozoic time by stocks, dikes, and sills of granite porphyry and, after deep erosion, were covered by a thick series of Cretaceous (Comanche) beds. These have in greater part been eroded away from the productive area of the district.

Structurally the district is characterized by numerous faults, some older and some younger than the Cretaceous beds. In some of the tilted fault blocks the strata are gently folded, but folding is a much less conspicuous feature of the structure than faulting.

The primary ores were deposited during or after the intrusion of the granite porphyry and before the deposition of the Cretaceous beds. Their age is therefore early Mesozoic. Their deposition was connected with a decided but not conspicuous contact metamorphism of the limestones, shown by the development within these of tremolite, diopside, garnet, and other silicates, generally in crystals of microscopic size. The ore bodies that first gave prominence to Bisbee are those in the Carboniferous and Devonian limestones, but recent developments are bringing to light important lenticular masses of ore in the Cambrian limestone, and a little ore has been found in the porphyry.

Very briefly stated, the larger structural features to which the occurrence of the ores is related are (1) the northwest-southeast Dividend fault, with a normal throw that has brought Paleozoic beds on the southwest side of the fissure against Pinal schist on the northeast side; (2) a small stock of granite porphyry intruded on the line of the fault and invading the contiguous schist and Paleozoic beds; (3) an open synclinal structure in the down-faulted Paleozoic beds, which is such that these dip in part toward the porphyry stock and in conjunction with the fault plane form a trough pitching to the southeast; and (4) a gentle tilt to the southeast, as shown by the present slope of the pre-Comanche erosion surface. The ore bodies occur in the down-faulted fragment of a syncline, are disposed in roughly semicircular fashion around the porphyry stock, and have radial prolongations along certain zones of fissuring.

While very irregular in form, the ore masses as a rule are roughly lenticular and tend to conform with the bedding of the limestones. The average thickness of all the ore bodies has been calculated by the engineers of the Copper Queen Co. to be about 33 feet. The shape

and position of many of the bodies, however, are determined by zones of fissuring and by the form of intruded porphyry masses, many of which do not extend directly upward to the surface. With possibly a few relatively unimportant exceptions, the known Bisbee ore bodies were originally deposited as metasomatic replacements of the limestones. In many of the ore bodies in the Abrigo limestone the positions of former bedding planes are clearly shown by a banding in the ore.

At the Copper Queen mine, near the northwest end of the structural trough, the ore bodies came to the surface. As development was pushed south and east, around and beyond the exposed porphyry mass of Sacramento Hill, through the Holbrook, Spray, Irish Mag, Gardner, Oliver, Lowell, Hoatson, and Junction shafts, the ore was found at greater depths. The great ore body of the Junction mine of the Calumet & Arizona Co., south of Sacramento Hill, whose existence was unknown when Professional Paper 21 was written, extends from a point 10 feet above the 1,300-foot level to the 1,500-foot level. It is 500 feet long and from 10 to 120 feet wide in plan, part of this width being due to duplication by faulting. South of the curved chain of mines mentioned lie the Briggs and other important ore bodies connected with zones of north-northeast and south-southwest fissuring in the limestone. In the Briggs mine the ore bodies grade outward into a huge partly oxidized mass of pyrite about 1,500 feet long and in places 800 feet wide.

In the Copper Queen, Lowell, and Hoatson mines the ore bodies are, as a rule, confined to the vicinity of intrusive masses of porphyry. In the Junction mine the connection between ore and porphyry is less close and in the Briggs mine no porphyry is known. Apparently the bodies of porphyry, like the fissures in the limestones, played an important part in controlling the movements of the ore-bearing solutions, but it is not believed that any considerable part of the ore constituents came from the porphyry masses now visible; the metallic elements and sulphur had a more distant source.

Up to the year 1904 nearly all the copper obtained at Bisbee came from oxidized or enriched ore. Of late years, however, primary ores have become very important. The Junction ore body, in which the present stopes average over 9 per cent of copper, is a nearly solid mass of sulphides that are mostly primary. The huge pyritic mass of the Briggs mine, with its included bodies of more cuprififerous material, is largely primary, and the ore lenses in the Abrigo limestone have, as a rule, undergone no enrichment.

The most abundant sulphides in the primary ore are pyrite and chalcopyrite. With these may be associated considerable bornite and in certain ore bodies magnetite. Of late years both sphalerite and galena have been found in considerable quantity near the porphyry of

Sacramento Hill, but these minerals are not widely distributed in the copper ores. No pyrrhotite has been noted.

The altitude of this district ranges from 5,000 to 7,400 feet above the sea. The average rainfall is about 17 inches and the surface of the ground water as a rule lies deep. Water was reached in the Lowell mine at a depth of 1,100 feet. Afterward the Junction shaft, 1,800 feet deep, drained the Lowell. For a time, when the lower Junction levels were kept open, the pumps raised over 6,000,000 gallons in 24 hours.

The natural ground-water surface and the lower limit of oxidation are neither coincident nor parallel. In general in the northern part of the productive area much enriched sulphide ore lies above the original water level, and in the southern part there is considerable oxidized material below it. In the Junction mine, for example, there is oxidized and leached material on the 1,500-foot level (corresponding to a depth of 1,750 feet in the Lowell shaft), and oxidized ore is mined in places on the 1,600-foot (bottom) level of the Lowell mine. The lower depth of oxidation ranges from 200 feet to at least 1,600 feet.

Although the relative importance of the enriched chalcocitic ores at Bisbee has been diminished by the discovery of large bodies of profitable primary ore, they still supply a large proportion of the total copper produced. The lower limit of enrichment is irregular and ill defined but, like the lower limit of oxidation, is deeper in the southern part of the productive area than in the northern part. Secondary chalcocite occurs in the bottom level of the Lowell mine (1,600 feet) and on the 1,300-foot level (1,400 feet deep) of the Briggs mine. How much deeper it may go is not known. In some places sulphide enrichment has worked down to the bottom of a pyritic ore body; in others it has worked around and under residual masses of unenriched pyritic material; and in parts of the Briggs mine large masses of leached and oxidized material rest directly on unenriched, low-grade pyrite. The enriching mineral is generally chalcocite. In some loose, friable ore the chalcocite may occur as thin shells around grains of pyrite and as a sooty interstitial powder. Elsewhere the replacement is more nearly complete, the original chalcopyrite and much or all of the pyrite having been converted into massive chalcocite. Secondary chalcopyrite has been noted,¹ but the greater part of this mineral is probably a primary constituent of the Bisbee ores.

The great depths to which oxidation and enrichment have penetrated at Bisbee and the inclined position of these zones of alteration with reference to the present underground water level and their approximate parallelism with the old pre-Comanche erosion surface indicate that much of the oxidation and enrichment were effected before the deposition of the Cretaceous formations.

¹ Ransome, F. L., *The geology and ore deposits of the Bisbee quadrangle, Arizona*: Prof. Paper U. S. Geol. Survey No. 21, 1904, p. 132.

GLOBE AND MIAMI, ARIZONA.

For the following note I am also indebted to Mr. Ransome, who studied the Globe district¹ some years ago and who is now investigating the Miami copper deposits.

THE GLOBE AND MIAMI DISTRICTS, ARIZONA.

By F. L. RANSOME.

In the Globe quadrangle, which includes the Miami district, a pre-Cambrian crystalline complex, consisting of Pinal schist and various granitic intrusives ranging from quartz diorite to true granite, is unconformably overlain by a thick series of Paleozoic beds. The stratigraphic column as revised after recent work in the adjoining Ray quadrangle is as follows:

Pre-Mesozoic stratigraphic column in the Globe region, Arizona.

Erosion surface.	Feet.
8. Thick-bedded gray limestone ² (Carboniferous).....	1,000
7. Thin-bedded limestone ² (Devonian).....	325
6. Quartzite ² (Cambrian).....	400
5. Cherty, dolomitic limestone ² (Cambrian).....	250
4. Dripping Spring quartzite.....	450
3. Barnes conglomerate.....	Cambrian or older { 10-55
2. Pioneer shale.....	
1. Scanlan conglomerate.....	
	200
	1-6

These rocks were extensively intruded, probably during the Mesozoic, by diabase, largely as great irregular sills, and were invaded also by certain masses of granite and quartz monzonite, including probably the Schultze granite, although this particular mass is not now in contact with the sedimentary series. All the rocks mentioned were covered wholly or in part by a thick flow of dacite, probably in early Tertiary time.

These rocks are cut by numerous faults, some older and some younger than the dacite.

The copper deposits occur (1) as lodes in schist, quartzite, limestone, and diabase, which, where they pass through or alongside of limestone, as in the Old Dominion mine, may be connected with large replacement bodies in that rock; (2) as disseminations of chalcocitic ore in the Pinal schist near the Schultze granite (Miami and Inspiration mines); (3) as secondary deposits of chrysocolla in dacite tuff (Black Warrior mine) or in fissures (old Live Oak and Keystone workings).

¹ Ransome, F. L., *Geology of the Globe copper district, Arizona*: Prof. Paper U. S. Geol. Survey No. 12, 1903; *Globe folio* (No. 111), *Geol. Atlas U. S.*, U. S. Geol. Survey, 1904.

² Names will be given to these formations in a forthcoming publication.—F. L. R.

The primary ore of the lodes consists essentially of pyrite and chalcopyrite, with bornite and specularite¹ of less regular or less abundant occurrence and galena and sphalerite rather rare. In the disseminated deposits in schist the primary metallic minerals are pyrite and chalcopyrite with a little molybdenite.

The disseminated primary metallization was undoubtedly connected with the intrusion of the Schultze granite, the constituents of the sulphides probably emanating from the magma reservoir that supplied that rock. The lode ores were also deposited at high temperature and may also be genetically connected with the granitic magma. They are, however, more closely associated with the diabase, and possibly this rock had some share in their genesis. The known ore bodies in limestone have been modified by secondary processes, but their original deposition by replacement was apparently not associated with any important metamorphism of the adjacent limestone.²

The altitude of the Globe quadrangle ranges from 3,000 to 7,850 feet and the average annual precipitation is between 13 and 20 inches. The ground-water level is in general deep, although in parts of the areas occupied by the Quaternary Gila conglomerate water is abundant within moderate distances from the surface. In the Old Dominion mine the original water level was probably between 700 and 800 feet in depth and a large part of the present influx is derived from workings that tap the conglomerate-filled valley of Pinal Creek. In the Miami-Inspiration group of mines the underground water level is not very well defined. Generally some water appears below a depth of 400 feet, but as a rule water is not abundant at depths less than 900 feet.

The ore bodies in limestone of the Old Dominion and neighboring mines have been nearly exhausted. They were large irregular masses of oxide and carbonate ore associated with much limonite and hematite. In the lodes connected with these masses oxidized ore prevails generally to a depth of 700 to 800 feet but extends much deeper, as was predicted in 1903,³ in the much-faulted ground under the Gila conglomerate, in the western part of the mine, where it is found on the 1,600-foot or bottom level about 1,200 feet below the surface. It is thus highly probable that much of the oxidation and enrichment at the Old Dominion lode was effected before the deposition of the Gila conglomerate.

¹ This mineral had been seen at Globe only in association with oxidized ores when Professional Paper 12 was written.—F. L. R.

² L. C. Graton (Mineral Resources U. S. for 1907, pt. 1, U. S. Geol. Survey, 1908, p. 596) has stated that the ores in limestone are believed to be of contact-metamorphic origin. I am not in accord with this statement.—F. L. R.

³ Ransome, F. L., Geology of the Globe copper district, Arizona: Prof. Paper U. S. Geol. Survey No. 12, 1903, p. 148.

Under the oxidized ore in the Old Dominion and adjacent lodes, mainly in diabase, are large bodies of chalcocitically enriched ore which grade irregularly downward into pyrite or into pyritic ore containing chalcopyrite, bornite, and specularite. In places enrichment has not penetrated below 800 feet, but elsewhere it goes much deeper.

The disseminated deposits near Miami, about 6 miles west of Globe, have been proved during the last few years to be of great economic importance. Churn drilling and mining exploration have shown the existence of a chain of large ore bodies extending in a gentle curve from the Miami mine on the east through the Inspiration, Keystone, and Live Oak mines to the west. The extreme western limit of this ore belt is as yet undetermined. The total length of this chain as at present developed is 2 miles, the maximum width is one-fourth mile, and the greatest thickness of ore along any one vertical line is about 300 feet. Estimates by the engineers of the various mines give a total of 80,000,000 to 90,000,000 tons of ore averaging between 2 and 2.5 per cent of copper.

As a whole, the ore bodies form an irregularly undulating ribbon of very uneven thickness. The distance from the surface of the ground to the top of the ore varies widely from place to place and is not definitely related to the present topography, which apparently is of later development than the main period of enrichment. At the Miami mine the depth to ore is in general between 200 and 400 feet, on the Inspiration ground it ranges from 50 to 600 feet, and on the Live Oak ground it reaches 1,000 feet. The ore dips generally east in the Miami mine, is on the whole nearly horizontal in the Inspiration mine, but turns down to the west in the Keystone, and this westerly dip increases to 40° or 45° in the Live Oak ground. East of the Keystone a zone of strong faulting has stepped down the ore, and at the Miami mine another fault cuts off the ore by bringing the Gila conglomerate down against the schist. There are other important faults in the district, but these can not be described in this brief note.

The surface of demarcation between the leached, more or less rusty, barren schist and the top of the ore is definite, and in many places there has been some slipping between the capping and the ore. The downward change from ore (above 1.3 per cent copper) to primary material (less than 1 per cent copper) is less definite but takes place within a few feet.

The country rock is in general Pinal schist, but good ore occurs also in dikes and small offshoots that extend into metallized schist from the main granite mass, which grades into granite porphyry on its margins. Over much of the ore-bearing ground this granite porphyry is the surface rock, the ore occurring in the schist beneath it. Clearly this part of the porphyry was intruded as a flat-lying sheet.

In general the unmetallized Pinal schist is a bright-gray fissile rock, splitting with a lustrous, satiny sheen and showing considerable variations in color, texture, and degree of metamorphism or crystallinity. The essential constituents are quartz, muscovite (sericite), a little microcline and plagioclase, magnetite, zircon, tourmaline, hornblende, biotite, and chlorite. As a whole, the Pinal schist was derived by metamorphism from arkosic sedimentary beds, although it includes here and there a little material of probable igneous origin.

During the primary period of metallization pyrite, chalcopyrite, a little molybdenite, and quartz were deposited in the fractured schists, partly in fissures an inch or so wide but chiefly in much smaller cracks or along cleavage planes. During the period of enrichment the downward-moving cupriferous solutions replaced the chalcopyrite and pyrite wholly or in part by chalcocite.

Final expression of opinion as to the geologic date of the principal enrichment is withheld, but a preliminary review of the evidence strongly suggests that the enrichment antedated the deposition of the Gila conglomerate and may possibly be older than the dacite. Probably the process has continued to the present day, but where erosion has overtaken the chalcocite zone enrichment apparently has been temporarily checked by the fact that little pyrite is available to form strongly acid solutions and the copper, instead of migrating downward, remains near the surface, coloring the rocks brilliantly with chrysocolla and carbonates. As a rule, the largest ore bodies are not found under those surface rocks that are most vividly colored by copper compounds or by iron oxide.

RAY, ARIZONA.

By F. L. RANSOME.

The disseminated copper deposits of Ray are about 20 miles southwest of Globe, in the hilly depression drained by Mineral Creek, between the Dripping Spring and Tortilla ranges.

The geologic formations are in general the same as those in the Globe quadrangle, the Pinal schist at Ray being intruded by two varieties of granite porphyry, one of which very closely resembles the porphyritic facies of the Schultze granite.

The ore bodies are mainly in the schist, although masses of granite porphyry within the generally metallized area have also been converted to ore.

Within the productive area the altitude ranges from 1,950 to 2,900 feet above sea, and most of the hills are steep and rugged. The climatic conditions are similar to those at Globe. Little information is available concerning the level of ground water, which is below the principal mine workings. Most of the water that enters the mines appears to be seepage from Mineral Creek and from its tributary, Copper Creek.

The ore bodies underlie a group of more or less rusty hills stained here and there with salts of copper. The principal area showing this alteration is of elongated oval shape and extends west-northwestward from Mineral Creek for about $2\frac{1}{4}$ miles with a maximum width of a little more than half a mile. Within this area churn drilling and mining have shown the presence of a continuous ore body about 8,000 feet long and 2,500 feet in greatest width. As at Miami, the layer of ore has many irregular undulations that apparently have no dependence on the present topography and varies much in thickness. The average thickness of the ore body is 101 feet; the average thickness of overburden 250 feet. The depth to ore varies from 10 to 300 feet and the thickness of the ore from 0 to 400 feet. Chalcocite has been reported from one drill hole to a depth of 715 feet and the ore extends under Humboldt Hill to a depth of 700 feet. The quantity of ore in the Ray ore body as calculated by the mine engineers is over 83,000,000 tons averaging 2.17 per cent of copper, with over 500,000 tons of considerably higher grade.

The relations of the ore to the oxidized leached capping and to the underlying primary material are similar to those at Miami. The ore constituents in the two districts are the same. In both districts the primary metallization continues to unknown depths. As at Miami, the greater part of the chalcocite is disseminated through the schist (or porphyry) in small specks or in minute veinlets with quartz; but here and there are veinlets several inches wide in which the original chalcopyrite and pyrite have been partly or wholly altered to massive chalcocite.

Pyrrhotite, sphalerite, and galena, so far as known, do not occur in the disseminated copper deposits at Ray or Miami.

MORENCI, ARIZONA.

The Morenci district, Arizona,¹ is an area of pre-Cambrian granite and quartzitic schists above which rest unconformably about 1,500 feet of Paleozoic sandstones, limestones, and shales that are locally overlain by Cretaceous shales and sandstone. These rocks are intruded by masses of granitic and dioritic porphyries, which form stocks, dikes, laccoliths, and sheets. All these rocks have participated in an uplift and a warping or doming that was succeeded by much faulting, which took place during latest Cretaceous or earliest Tertiary time. Surrounding the domed area of older rocks are great masses of Tertiary lavas consisting of basalt and rhyolite, with some andesite.²

The ore bodies are veins and disseminated deposits in the granite and monzonite porphyry and contact-metamorphic deposits in the

¹ Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1906.

² Idem, p. 17.

pyrite, and rarely zinc blende and pyrrhotite accompany these sulphides. Galena and its oxidation products occur in irregular lodes within the metamorphic area, principally at some distance from the porphyry masses. Gold ores, formerly exploited, occur mainly in the form of blanket lodes, the gold being associated with lead carbonate.

Of many superficial showings of copper carbonates none has been developed profitably, but oxidized ores of relatively high grade have been discovered in the Alpha mine of the Giroux Co., at considerable depth. This ore body is inclosed by metamorphosed and thoroughly oxidized sedimentary rocks that lie several hundred feet from the nearest mass of porphyry.

The present importance of the district centers in the low-grade disseminated ores in porphyry. The igneous rock was locally fractured after its intrusion, and great masses of it became infilled with veinlets of quartz carrying pyrite and chalcopyrite. Even away from the fractures the porphyry was charged with sulphides and the rock was greatly altered, with abstraction of lime, magnesia, soda, and iron and with noteworthy addition of potash. These losses and gains involved the destruction of hornblende and lime-soda feldspar and the formation of mica, including brown mica and sericite. The outcrops of the ore masses are yellowish or less commonly red and are said to carry not over 0.5 per cent of copper. There is an abrupt change from this capping to soft bluish-white porphyry ore, which carries disseminated sulphide minerals, including copper glance, as films coating grains of pyrite and chalcopyrite or, less commonly, completely replacing such grains.

One company, the Nevada Consolidated, has developed about 49,000,000 tons of disseminated ore, the average being 1.7 per cent copper. The variations in depth are indicated in three sections as follows:¹

Thickness, in feet, of capping and of ore in workings of the Nevada Consolidated Co., Ely, Nev.

Section.	Average thickness of direct capping.	Average thickness of profitable ore.
Eureka.....	87.1	190
Hecla.....	101.4	280.3
Liberty.....	154.7	193.3
Average.....	102.5	217.9

The profitable ore is known to extend locally to depths about 600 feet below the surface. In one place a hole was put down nearly 400 feet below the ore body in material which carried less than 0.4 per cent of copper.

¹ Fifth Ann. Rept. Nevada Consolidated Copper Co., for 15 months ended Dec. 31, 1911, p. 8.

The gold and silver content of the disseminated ores is considerable. In 1911 the average per ton was 0.013 ounce gold and 0.079 ounce silver. Although less than 60 per cent of the precious metals was saved, their value recovered was 17.35 cents a ton.

A composite analysis of 1,000 samples of ore from the Ruth mine shows, as stated by Lawson, sulphur, 6 per cent; iron, 5.3 per cent; and copper, 2.61 per cent, which may be calculated as equivalent to pyrite, 10 per cent; chalcopyrite, 1.8 per cent; and chalcocite, 2 per cent.

It may be stated as a general truth that any porphyry carrying more than 1 per cent of copper owes its grade to the presence of chalcocite, the enrichment having resulted from precipitation of this mineral out of solutions derived from overlying material.

In the porphyry mines the lower limit of complete oxidation is everywhere considerably above the water level, the difference in elevation being about 250 feet in the Ruth mine. While most of the material carrying chalcocite lies above standing water, the bottom of the ore seems to bear no definite relation to the water table. The greatest depth of porphyry ore is about 600 feet, but in the Alpha mine, which lies outside of the porphyry ore, enriched ore was found between the 700 and 1,200 foot levels. Here the water stands somewhat more than 1,000 feet below the surface and most of the lode material is fully oxidized and leached to this depth.

SANTA RITA AND HANOVER DISTRICTS, NEW MEXICO.

The Santa Rita and Hanover districts, New Mexico,¹ are adjacent and show similar geologic features. The country is an area of Carboniferous and older sedimentary rocks, consisting of limestone, quartzite, and shale. These are intruded by granodiorite, quartz monzonite porphyry, and related igneous rocks, and along the intrusive contacts garnet zones have developed. Considerable masses of magnetite, pyrite, and zinc blende are present. Pyrrhotite² is found in the Hanover district, and sphalerite has been mined to some extent for zinc.³

At Santa Rita most of the copper occurs as native metal, oxide, or sulphide in altered porphyry. Chalcocite with kernels of pyrite is present both in the quartzite and the porphyry.⁴

As stated by Graton, it is certain that much of the copper that now exists as native metal or oxide was not precipitated on pyrite but must have been deposited from solution in open spaces and in porphyry as replacement along fissures.

¹ Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., *The ore deposits of New Mexico*: Prof. Paper U. S. Geol. Survey No. 68, 1910, p. 305.

² Idem, pp. 53, 58, 81.

³ Idem, p. 309.

⁴ Idem, p. 62.

Whether or not a mingling of solutions containing hydrogen sulphide or some other soluble sulphide with those containing the copper caused this precipitation is unknown.¹

The presence in chalcocite ores of cores and kernels of pyrite and, outside the ore bodies, of pyrite in masses similar in distribution to the bodies of ore, as well as in a more disseminated state, and all more or less coated with chalcocite, makes it certain that at least a great part of the chalcocite was precipitated by and replaced pyrite.²

In the disseminated ores on the Chino ground some 55,000,000 tons of ore averaging 2.24 per cent copper are said to be developed. Most of it is near the surface. About 70 per cent, it is said, may be mined with steam shovels. The average thickness of the capping, according to B. S. Butler,³ is 82 feet, and the average thickness of the ore below the capping is 107 feet.

The ore is somewhat richer than the disseminated ore in several other districts in the Southwest, but no data are available to show that zinc blende has favorably affected the grade of the concentration. I am informed that sphalerite is present in some of the deposits, but that little or none has been observed in the ore directly below some of the important bodies of disseminated ore.

JEROME, ARIZONA.

By F. L. RANSOME.⁴

At Jerome faulting has effected the relative elevation and exposure of a mass of pre-Cambrian schist, within which the principal ore bodies thus far developed are those of the United Verde mine. On the hillside just west of the mine the schist is unconformably overlain by Cambrian, Devonian, and Carboniferous beds.

In the vicinity of the mine the schist stands nearly vertical, with rather rough irregular cleavage, and strikes a little west of north. At least three varieties are distinguishable—(1) a green rock, schistose on its margins but grading into massive material, which is evidently an altered dioritic intrusive; (2) a rough gray schist with abundant phenocrysts of quartz, apparently an altered rhyolite; and (3) satiny greenish-gray, very fissile sericitic schist that may be a metamorphosed sediment. The ore occurs in varieties 2 and 3, the main belt of dioritic rock (1) lying just west of the ore bodies. The ore is said to follow as a rule the layers of fine sericitic schist.

The ore shoot as a whole is of oval plan, its total horizontal length being about 1,300 feet and its greatest width 700 feet. Its general trend is north-northwest and it pitches in that direction at an angle

¹ Lindgren, Waldemar, Grafton, L. C., and Gordon, C. H., The ore deposits of New Mexico: Prof. Paper U. S. Geol. Survey No. 68, 1910, p. 316.

² Idem, p. 315.

³ Butler, B. S., Mineral Resources U. S. for 1910, pt. 1, U. S. Geol. Survey, 1911, p. 205.

⁴ Based on a brief visit in 1912.

of 45°. It has been worked to a vertical depth of 1,200 feet with no sign of approaching exhaustion. This great shoot is in reality a complex of smaller but nevertheless large irregular or lenticular ore bodies, apparently related in part to cross fissuring but showing a general tendency toward parallelism with the schistosity.

The important ore constituent is chalcopyrite, associated with varying proportions of pyrite and sphalerite. Bornite has been reported but was not noted in 1912. Neither galena nor pyrrhotite was observed at the time of visit. The sulphides occur partly in small irregular fractures and along planes of schistosity, but to a large extent they have metasomatically replaced the schist, particularly the fine-grained sericitic variety. The ore contains very little vein quartz or other gangue mineral.

The sulphides mentioned are primary and were deposited in pre-Cambrian time.

Oxidized ore, containing malachite, azurite, and cuprite, extended to a depth of about 400 feet and in its upper part was comparatively rich in gold. Native copper was nowhere abundant. Below the level of complete oxidation there was, according to H. J. Stevens,¹ some chalcocitic enrichment with a relatively high proportion of silver, but I was informed at the mine that the chalcocitic zone was not of great economic importance and soon gave place to primary ore.

BURRO MOUNTAIN DISTRICT, NEW MEXICO.

The Burro Mountain district is in Grant County, southwest New Mexico. The country is arid and lies 5,000 to 8,000 feet above the sea. The main mass of the mountains² consists of pre-Cambrian granite and pegmatite and a dioritic rock which locally is gneissic. These rocks are intruded by monzonite porphyry.

The most important deposits are impregnations and replacements along irregular fractures and zones of crushing. Silica and cupriferous pyrite have been introduced and constitute the primary lodes. Practically all the workable ores are the result of enrichment of this lean pyritic material. Rich oxidized minerals—native copper, cuprite, melaconite (?), chrysocolla, melanochalcite (?), malachite, and azurite—are found at or near the surface, but at greater depth chalcocite and chalcocite-coated pyrite are the ore minerals, and at a still lower level these give way to unaltered pyrite.

In the principal mine at Leopold, which belongs to the Burro Mountains Mining Co.—

the zone of impoverishment or leaching is in most places less than 50 feet deep. The ore on the first or 100-foot level contains more iron and less copper than that on

¹ Stevens, H. J., *Copper handbook*, 1909, p. 1269.

² Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., *The ore deposits of New Mexico: Prof. Paper U. S. Geol. Survey No. 68*, 1910, p. 320.

the 130-foot and 160-foot levels; in fact, it appears less enriched. It was reported in 1905 that the lowest or 210-foot level then being driven, had encountered low-grade pyritic ore under the enriched ore of the upper levels, but since then important discoveries have been announced.¹

According to S. S. Lang² the chalcocite ore ends very abruptly against the pyrite-chalcopyrite ore below.

In the district southeast of Leopold, according to Sidney Paige,³ the leached ground is 200 feet deep. From this the richer ores extend downward to a depth of 380 feet, where unaltered sulphides are encountered. The water level is variable—from 300 to 500 feet below the surface.

CANANEA, MEXICO.

Cananea, Sonora, Mexico, is 25 miles south of the international boundary and some 38 miles by rail from Bisbee, Ariz. The country is mountainous and the principal deposits are 5,200 to 6,500 feet above the sea. The climate, although arid, is somewhat more humid than that of Arizona.

The region has had a complex geologic history.⁴ An ancient granite is overlain by Paleozoic (?) quartzite and limestone and intruded by diabase, above which are rhyolitic tuffs and rhyolite. Intrusive masses of syenite and syenite porphyry are later than the sedimentary rocks and probably later than the tuffs, and large intrusive masses of diorite and diorite porphyry cut both tuffs and limestones. A later granite porphyry, a granodiorite, a quartz monzonite porphyry, and gabbro and diabase are found in intrusive masses.⁵

Contact metamorphism, with the development of heavy silicates and sulphides, has attended the intrusion of the diorite porphyry, the granodiorite, and the quartz porphyry. Contact-metamorphic deposits are numerous and important, but these are subordinate to the great lodes and disseminated ores in the sericitized and silicified phases of the diorite porphyry. The principal deposits of the latter class lie in a belt 1 to 2 miles wide and 6 miles long, which strikes a little north of west, significantly parallel to the great Eliza fault. The contact-metamorphic deposits are composed of chalcopyrite, sphalerite, bornite, magnetite, hematite, and galena in a gangue of garnet, calcite, hornblende, pyroxene, and other heavy silicates. In general, these deposits show chalcocite enrichment to only very shallow depths.⁶

¹ Lindgren, Waldemar. Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: Prof. Paper U. S. Geol. Survey No. 68, 1910, pp. 322-323.

² Lang, S. S., The Burro Mountain copper district: Eng. and Min. Jour., vol. 82, 1906, p. 396.

³ Paige, Sidney, Metalliferous ore deposits near the Burro Mountains, Grant County, N. Mex.: Bull. U. S. Geol. Survey No. 470, 1910, p. 131.

⁴ Emmons, S. F., Cananea mining district of Sonora, Mexico: Econ. Geology, vol. 5, 1910, p. 312.

⁵ Weed, W. H., The Cananea copper deposits: Eng. and Min. Jour., vol. 74, 1902, pp. 744-745; The Cananea district: Trans. Am. Inst. Min. Eng., vol. 32, 1902, p. 428; The Cananea ore deposits: Eng. and Min. Jour., vol. 76, 1903, p. 383. Austin, W. L., The ore deposits of Cananea: Eng. and Min. Jour., vol. 76, 1903, pp. 310-311. Hill, R. T., The ore deposits of Cananea: Idem, p. 421; Cananea revisited: Idem, pp. 1000-1001.

⁶ Emmons, S. F., op. cit., p. 355.

The ores in porphyry are composed chiefly of pyrite, chalcopyrite, sericite, kaolin, quartz, and other minerals. Zinc blende, although locally abundant, is erratic in distribution. In these ores chalcocite enrichment is very extensive.

Many of the ore bodies are marked by conspicuous gossan immediately or not far above the deposits. This, I believe, is invariably true of the garnetiferous ores in altered limestone, although in the latter oxidation extends only to shallow depths. Some richer ores of this type are seamed and coated with chalcocite, and possibly some chalcopyrite in these deposits is secondary, but these ores are nevertheless workable at several places, in what appears to be their primary concentration.

In the West Cobre Grande and Kirk mines the development is in both diorite porphyry and limestone. The ores are generally of good grade, but at the 200-foot level there is an apparent falling off in the amount of chalcocite and an increase in the proportion of zinc in the ore, which indicates sulphide enrichment.¹

The most important deposits of the district are those of the Capote basin, which are almost exclusively fractured zones in sericitized porphyry. The primary ores consist mainly of pyrite with a small admixture of chalcopyrite and in places considerable zinc blende. Their introduction was accompanied by extensive sericitization and silicification of the adjoining country rocks. They occur in closely spaced fractures or shear zones that traverse both eruptive and sedimentary rock, and they are disseminated in porphyry throughout the rock, adjoining fractures. The tenor in copper is so low that it is doubtful if the primary ore could have been mined at a profit if it had not received additional copper by downward migration or sulphide enrichment.²

The surface is conspicuously altered by oxidation, which has readily attacked the hydrothermally altered pyritized area. Along the Capote fault zone the ore body is capped by gossan, which lies above porphyry and quartzite. A chimney of ore, large on level 1, was followed down to level 7, where it had decreased in size. This chimney of ore appears to represent a zone of intense fracturing and one peculiarly favorable to concentration. Some of the fracturing is later than primary deposition, for traces of enrichment are found down to the seventh level.³

The Oversight ore body is capped by porphyry that is silicified but only slightly stained with iron. The chalcocite ore is found 260 feet below the surface and extends downward at least 300 feet deeper, but its lower limit had not been determined in 1907.

¹ Emmons, S. F., *op. cit.*, p. 340.

² *Idem*, p. 341.

³ *Idem*, p. 345.

The Veta Grande ore body has produced remarkably rich oxidized ore, chiefly cuprite and native copper. Rich ore of decreasing tenor was found as deep as the 500-foot level. "In the middle levels there is much enrichment by chalcocite, but this enrichment has apparently not extended to the lowest level."¹

NACOZARI, MEXICO.

Nacozari, Sonora, Mexico, is 75 miles south of the international boundary line, in a region of hills and low mountain ranges much like those of Arizona. The country rock consists of volcanic tuffs, breccias, and other igneous rocks, with which are associated subordinate limestones and other sedimentary rocks.²

The most important mines belong to the Moctezuma Copper Co., controlled by Phelps, Dodge & Co. The principal developments are those of Los Pilares mine, at the end of a tunnel about a mile long, which intersects a shaft 600 feet below the surface. The largest deposit is a great semicircular body of relatively low grade ore that appears to conform with a curving fractured mass of monzonite (?) which follows a sheeted zone of faulting and a faulted diabase dike that intersect nearly at a right angle.

The ore in depth is composed of brecciated monzonite (?) the small fragments of which are cemented by iron and copper sulphides. The principal sulphides are pyrite and chalcopyrite, which in the richer ore are coated with bornite and a relatively small amount of chalcocite. In places the ore contains a little zinc, but lead is not reported to be present. At the surface the outcrop is iron-stained gossan that has locally weathered into the pillars from which the mine derives its name.³ As in some other arid regions, the iron ore has become dehydrated at the surface, forming specularite. The stopes of richer ore extend from a short distance below the 100-foot level down nearly to the 500-foot level. Below this the ore is said to be falling off in grade.

It is thus evidently to secondary enrichment that it owes its quality as pay ore. Above these limits the copper is leached out; within them is the greatest concentration of the richer sulphides and, while they can still be observed in the lower levels of the mine, it is evident to the eye that they are in decreasing proportion.⁴

According to W. L. Tovote⁵ the chalcocite zone is insignificant.

¹ Emmons, S. F., *op. cit.*, p. 347.

² Emmons, S. F., Los Pilares mine, Nacozari, Mexico: *Econ. Geology*, vol. 1, 1906, pp. 629-643.

³ *Idem*, p. 631.

⁴ *Idem*, p. 636.

⁵ Tovote, W. L., *Magmatic origin of ore-forming solutions: Min. and Sci. Press*, vol. 104, 1912, p. 602.

SILVERBELL, ARIZONA.

The deposits at Silverbell, Ariz.,¹ are in an area of Paleozoic rocks, including limestones, complexly cut by an alaskite porphyry intrusion and by andesite and trachyte dikes and covered by andesite, rhyolite, basalt, and other rocks. Garnet contact zones are developed in limestone near the porphyry. The ore bodies, as stated by Tolman, include contact-metamorphic deposits in limestone, disseminations in porphyry, and fissure veins.

The contact-metamorphic deposits supply most of the ore (1909). These deposits carry chalcopyrite, pyrite, quartz, molybdenite, and occasionally wulfenite. A considerable proportion of this ore is oxidized. Some lean chalcocite deposits are disseminated in porphyry.

SAN FRANCISCO REGION, UTAH.

By B. S. BUTLER.

The San Francisco region, Utah, is a large mineralized area in the San Francisco and adjacent ranges in Beaver County, Utah. The sedimentary series consists of Paleozoic limestones, shales, and quartzites. These have been covered by a thick series of lavas of intermediate composition. These formations have been intruded by quartz monzonite and allied rocks.

The ore deposits may be divided into three general types—(1) replacement deposits in fissures in the quartz monzonite; (2) replacement deposits in the limestone, including contact deposits and replacement deposits along fissures, and (3) replacement fissure deposits in the lavas.

Of the replacement deposits in fissures in the quartz monzonite the ore zone in the Cactus mine is the most important. This consists of a brecciated zone of quartz monzonite that has been greatly altered and replaced by the ore minerals. These consist of the sulphides, pyrite and chalcopyrite, with small amounts of tetrahedrite and galena and abundant specularite in a gangue of quartz, sericite, tourmaline, impure siderite, anhydrite, and some barite. Oxidation has not extended below 100 feet and for the most part is confined to a space within 50 feet of the surface. The principal minerals resulting from the oxidation are limonite, azurite, and malachite, with some native copper. Chalcocite is almost and possibly entirely absent from the deposit.

The O K mine, in the Beaver Lake Range, also works a deposit that lies in quartz monzonite and that is similar to the deposit worked by the Cactus mine except that it contains no specularite and that

¹ Tolman, C. F., Copper deposits of Silverbell, Ariz.: Min. and Sci. Press, vol. 99, 1909, pp. 710-712.

the gangue is quartz and sericite. In this deposit oxidation has extended to much greater depth, fully 200 feet, and covellite and chalcocite replace pyrite and chalcopyrite. The only apparent reason for the difference in the secondary ores here and in the Cactus mine is the presence in the latter of carbonate, which has probably prevented or retarded the downward movement of the copper content of the ores.

The typical contact deposits are composed of pyrite, chalcopyrite, magnetite, and sphalerite in a gangue of garnet, tremolite, and other silicates. In general oxidation has not extended to great depth, probably owing to the massive character of the deposits. The richer ores, however, have resulted from concentration in the oxidized zone.

The replacements along fissures in the limestone are typically lead-silver deposits containing minor amounts of copper and zinc. The ores are largely oxidized to the depth of present developments—500 to 600 feet. The metal-bearing minerals are principally carbonates but include minor amounts of sulphates.

The Horn Silver mine is on the most important deposit in the volcanic rocks. This deposit occurs along a fault that has thrown the lavas down against the Paleozoic limestone. The lavas have been considerably shattered along this fault, especially in the vicinity of minor cross faulting, but the limestone is relatively massive. The ore deposits have formed largely as a replacement of the brecciated lava. The primary ore consists of pyrite, galena, sphalerite, and minor amounts of other metallic minerals in a gangue of quartz, sericite, and partly altered lava. In the oxidized zone the ores are characteristically sulphates, anglesite being the principal mineral in much of the lead ore. Complex sulphates, such as beaverite, plumbojarosite, and jarosite, are rather abundant, and the oxidized copper ore carries much brochantite. Zinc is not abundant in the oxidized ores, though some carbonate of zinc occurs. In the secondary sulphide zone the copper ore consists of covellite and chalcocite, partly or wholly replacing sphalerite, wurtzite, pyrite, and, to a slight extent, galena. Rich copper ores were mined to a depth of about 750 feet, and enrichment along favorable channels has extended much deeper. The rich zinc ores of this mine are composed of sphalerite and wurtzite, together with the sulphides of other metals in variable quantities. The wurtzite is apparently secondary, commonly forming around cores of sphalerite, and the richer ores have resulted from the addition of the zinc in the wurtzite. Normally the zinc enrichment extends to greater depth than the copper enrichment, and secondary zinc sulphide has been replaced by secondary copper sulphides.

The Beaver Carbonate mine, another replacement deposit in the volcanic rocks, is similar in occurrence to the Horn Silver deposit,

except that both walls are of the volcanic rock. In this deposit enrichment has been slight, apparently owing to the presence of a local water table very near the surface.

SHASTA COUNTY, CALIFORNIA.

The copper-bearing region of Shasta County, Cal.,¹ is an area of sedimentary rocks complexly intruded by several varieties of con-sanguineous igneous rocks. The oldest sedimentary series comprises the Kennett formation (Middle Devonian), which consists chiefly of black fissile shale, with scattered lenses of light-gray limestone and numerous gray or yellowish beds of tuffaceous material. Overlying the Kennett formation unconformably is the Bragdon formation (Mississippian), which consists chiefly of black and gray shales, with thin interbedded layers of tuff and sandstone and bands of conglomerate. Above the Bragdon is the Pit shale, of Middle and Upper Triassic age, consisting chiefly of shales with interbedded layers of volcanic tuff.

The oldest igneous rock is an altered andesite called by Diller the meta-andesite, which underlies and is older than the Kennett and Bragdon formations. A massive, less-altered andesite (Dekkas andesite) overlies the Bragdon and underlies and grades into the Pit. Younger than all these rocks and cutting the latest of them, the Pit shale, are intrusives of soda-rich alaskite porphyry, or soda granite. The alaskite porphyry is cut by quartz diorite, which in turn is cut by acidic and basic dikes that are genetically very closely related to the alaskite porphyry and to the pegmatites of the region. These pegmatites, according to Graton,² are more acidic than the present quartz diorite and in places "pass over into siliceous masses that are virtually quartz veins and carry sulphides."

There are two centers of alaskite porphyry, and each is a center of ore deposition.

The important copper deposits consist of large masses of pyritic ore, surrounded in most places by alaskite porphyry but here and there extending into shale. The ores are of medium richness, yielding at present an average of about 3 to 3½ per cent of copper and \$1.50 to \$2 per ton in precious metals, generally about equally divided between gold and silver.³

The ores were probably formed about at the close of the Jurassic or the beginning of the Cretaceous. They are in part replacements in shattered zones of alaskite porphyry which is highly altered by sericitization (soda sericite). The deposits are mineralogically simple. Pyrite is the most abundant ore mineral, and chalcopyrite is the chief one that gives the ores their copper value. Sphalerite or zinc blende

¹ Diller, J. S., Redding folio (No. 128), Geol. Atlas U. S., U. S. Geol. Survey, 1906. Graton, L. C., The occurrence of copper in Shasta County, Cal.: Bull. U. S. Geol. Survey No. 430, 1910, pp. 71-111.

² Graton, L. C., op. cit., p. 88.

³ Idem, p. 89.

is also present in varying amount; on the average it possibly exceeds the chalcopyrite. Some galena is associated with the zinc sulphide, especially in the eastern districts of the region. The gangue minerals are gypsum, calcite, and barite. The minerals which have resulted from the alteration of the primary ore minerals include limonite, magnetite, wad; secondary chalcopyrite, bornite, and chalcocite; cuprite; native copper; small amounts of malachite and azurite; and several sulphates.

In some of the ore bornite, chalcocite, and chalcopyrite are intergrown. The two richer copper sulphides are very commonly intergrown with the chalcopyrite, in places inclosing it and in places being inclosed by it.

These two minerals were found in the deepest workings of the Afterthought mine at a depth of about 600 feet and in the deepest workings of the Bully Hill mine at 970 feet, as well as at higher levels. In places they are intergrown with and even entirely surrounded by barite, and there is no reason whatever to consider them as other than primary constituents of the ore. Both bornite and chalcocite, as well as chalcopyrite, however, are also formed in the upper portions of some of the ore bodies by the process of secondary enrichment, but almost all such occurrences can be readily distinguished from those in which the minerals are of primary origin.¹

The secondary zone was wonderfully productive of copper and silver at the Iron Mountain and Bully Hill mines, but at other mines it is either of little importance or practically absent. The secondary ores appear to have extended to no great depth and are now exhausted.²

YERINGTON, NEVADA.

The country at Yerington, Nev., is an area of schists and limestone with intrusive masses of granodiorite, or quartz monzonite, and related porphyries, which are overlain by a series of rhyolite flows and tuffs, bedded volcanic grits, andesite tuff, and andesite breccia, and an unconformably overlying flow of basalt.³

The copper deposits, according to Ransome,⁴ are (1) irregular bodies formed by metasomatic replacement of limestone and genetically associated with metamorphism of a kind usually attributed to the contact action of intrusive rock, (2) metasomatic vein deposits in altered limestone, and (3) metasomatic vein deposits in granodiorite.

To the first or contact-metamorphic class belong the deposits worked by the Bluestone, Mason Valley, and other mines. In the Bluestone mine the ore consists essentially of chalcopyrite dissemi-

¹ Graton, L. C., *op. cit.*, p. 105.

² Graton, L. C., *Mineral Resources U. S. for 1907*, pt. 1, U. S. Geol. Survey, 1908, p. 599.

³ Ransome, F. L., *The Yerington copper district, Nevada*: Bull. U. S. Geol. Survey No. 380, 1909, p. 99.

⁴ *Idem*, p. 116.

nated as grains and small irregular masses through limestone that has been altered to an aggregate consisting chiefly of a yellowish-gray epidote with subordinate calcite and quartz. A little garnet is present.¹ Zinc blende is not mentioned. In these deposits, as stated by Ransome—

Oxidation is not extensive and scarcely penetrates to the 100-foot level, while chalcopryite is present in the croppings. The products of oxidation are malachite (with possibly some brochantite and libethenite), azurite, cuprite, and chalcanthite. These are generally associated with sulphides, and there are no large masses of thoroughly oxidized ore. A little chalcocite occurs above the 100-foot level, but there has been no important enrichment through the secondary formation of this mineral. It is evident that the ore body as a whole is too solid to have been penetrable to any considerable depth by oxidizing solutions and that erosion has kept pace with the process of weathering.²

The vein deposits in limestone are represented by the Ludwig vein, which is composed mainly of coarse crystalline calcite carrying some garnet with pyrite and chalcopryite. Oxidation in this deposit has extended to a depth of about 500 feet and has produced ore of shipping grade. At the base of the oxidized zone there has been some chalcocite enrichment.³

The primary ore of the Mason Valley mine contains more pyrite with the chalcopryite than that of the Bluestone mine and appears to be generally of lower grade. Oxidation, however, has penetrated deeper and has effected some local concentration down to the No. 3 tunnel, although some sulphides occur at the surface. On the No. 3 level there is a considerable body of rich ore consisting of impure earthy cuprite with much disseminated native copper. The shape and extent of this body, which contains up to 20 per cent of copper, have not been fully ascertained. Chalcocite in a soft, sooty condition occurs sparingly, but there has been no important enrichment through the formation of this sulphide. The minerals noted in the oxidized zone are malachite, azurite, cuprite, native copper, limonite, gypsum, and chalcanthite.⁴

VANCOUVER, BRITISH COLUMBIA.

The copper deposits on the west side of Vancouver Island are located near contacts of granite and calcareous sedimentary rocks and are composed of pyrite, bornite, garnet, and other minerals. The ore of the Monitor mine is a mixture of chalcopryite, pyrrhotite, and coarse magnetite, filling interstices and holding unreplaced rock fragments.⁵

According to William M. Brewer,⁶ some of the deposits carry magnetite and gossan at the outcrop, and rich chalcopryite ore was found in one deposit within 6 feet of the surface.

¹ Ransome, F. L., *The Yerington copper district, Nevada*, Bull. U. S. Geol. Survey No. 380, 1909, p. 107.

² Idem, p. 108.

³ Idem, p. 117.

⁴ Idem, p. 110.

⁵ Weed, W. H., *The copper mines of the world*, New York, 1907, p. 222.

⁶ Brewer, W. M., *The copper deposits of Vancouver Island*: Trans. Am. Inst. Min. Eng., vol. 29, 1900, pp. 483-488.

SNOWSTORM LODGE, COEUR D'ALENE DISTRICT, IDAHO.

The Snowstorm lode,¹ 3½ miles east-northeast of Mullan, Idaho, is a wide zone of impregnation in Revett quartzite (pre-Cambrian) and conforms with the bedding, which strikes N. 60° W. and dips 65° SW. There is no pronounced fissuring along the lode, but microscopic study shows a network of fractures or invisible capillary openings which gave access to the ore-bearing solutions. The vein dips down the slope of the hill, and tunnel 3 is about 800 feet below the surface.

The ore is highly siliceous (over 90 per cent SiO₂) and is in wide demand for use in converter linings. It carried (1904) about 4 per cent copper, 6 ounces silver, and 0.1 ounce gold.

In its unoxidized form the best ore consists of quartzite so crowded with little specks and small irregular bunches of bornite, chalcocite, and chalcopyrite as to be dark gray or nearly black. The microscope shows that the ore minerals to some extent fill irregular microscopic fissures but that for the most part they have replaced the interstitial sericite and siderite of the country quartzite.

Comparatively little of the ore, however, remains in its sulphide condition. Most of it has been oxidized to cuprite and malachite. There is no well-defined zone of oxidation, most of the sulphide ore occurring in No. 2 tunnel [about 460 feet below the outcrop measured on the dip of 65°] and some carbonate in No. 3 tunnel [about 1,200 feet below the outcrop measured on the dip of 65°].²

COPPEROPOLIS, CALIFORNIA.

The rocks in the vicinity of Copperopolis, Cal., are metamorphosed igneous and sedimentary rocks of the "Bedrock series" and include the Mariposa slate, meta-andesites, and other rocks, cut by gabbro, hornblende, granodiorite, and serpentine.³ The ore occurs as overlapping lenses, many arranged en échelon, each lens being composed of a complex series of bands or veinlets of chalcopyrite and pyrite deposited mainly parallel to the foliation of the schist. In age the ore, according to Reid, is earlier than the gold-bearing veins of the Mother Lode region. These veins are associated with the acidic intrusives of this part of the Sierra Nevada, which are distinctly later than the copper ore.

The surface zone of oxidized ore is very shallow, 30 feet or less, and a zone of secondary enrichment is entirely lacking. This is no doubt due to the fact that the intense lateral pressure in the rocks has prevented the formation of a vadose circulation. The actual surface is characterized by extensive gossan, in which occur seams of malachite, often very rich, coating the schist. A very small amount of azurite occurs, particularly toward the south. In the Empire ground, south to the concentrator, cuprite is found. Some very rich ore of this kind has been mined within a few feet of the concentrator, to the north. In a small incline shaft a few feet south

¹ Ransome, F. L., and Calkins, F. C., The geology and ore deposits of the Coeur d'Alene district, Idaho: Prof. Paper U. S. Geol. Survey No. 62, 1906, p. 151.

² Idem, p. 152. The matter in brackets is mine.—W. H. E.

³ Reid, J. A., The ore deposits of Copperopolis, Calaveras County, Cal.: Econ. Geology, vol. 2, 1907, pp. 380-417.

of the Empire shaft cuprite appears as small flakes in the gliding planes of serpentine and talc. The ground to the south, from the Empire shaft to the gabbro boss, shows the largest amount of oxidized ore, due to the greater shattering of the rocks by the latest igneous intrusives.

Beneath this oxidized zone occur the original sulphides—chalcopyrite and pyrite in a gangue of country rock, the latter being usually chlorite schist. The richest ore is pure chalcopyrite; the copper content is lowered both by admixture of pyrite and of country rock. The presence of too much schist or other rock makes a low-grade concentrating ore; too much pyrite produces eventually waste material. Both the sulphide minerals, which occur relatively in all proportions, are found in thin veinlets or bands in the foliation planes of the serpentine and talc.¹

BOLEO, LOWER CALIFORNIA.

The Boleo mines, on the east coast of Lower California, are among the more important copper deposits in Mexico. According to Fuchs,² the country is an arid dissected plateau composed of trachytic tuffs and conglomerate, probably Tertiary, which are cut by intrusive trachyte. The ore beds, which conform with the strata, are gently inclined to the sea. There are three beds, each of which is in general from 2 to 8 feet thick, and the three lodes are separated by a few feet of clayey tuffs and conglomerates. The ore beds are altered clayey tuffs and the ore is scattered through the clay in small fragments and nodules, hence the name. The minerals include cuprite, atacamite, azurite, malachite, chrysocolla, crednerite, and salt.

Stevens,³ who writes later than Fuchs, states that chalcocite and covellite predominate, although the lowest bed, which is partly below the water line, carries oxides and carbonates also. At the bottom of each bed is 6 to 8 inches of rich ore, which was once sorted to run about 20 per cent copper. De Launay⁴ supposed that the ores were formed by processes of sedimentation, the mineral waters issuing at the time the volcanic sedimentary rocks were formed, but Weed⁵ suggests that they were formed by thermal waters after sedimentation.

BRADEN COPPER MINES, CHILE.

The mines of the Braden Copper Co. are in the O'Higgins province, Chile, in the Andes. The country rock is andesite surrounding a body of light-gray tuff, which is said to represent the crater of an ancient volcano.⁶ The diameter of the volcanic neck is about 4,000 feet and the periphery measures about 2½ miles. It is said to be of Tertiary age, presumably the later Tertiary.

The ore lodes are in and around the periphery of the crater, in andesite at its contact with tuff. The minerals are pyrite, magnetite,

¹ Reid, J. A., The ore deposits of Copperopolis, Calaveras County, Cal.: Econ. Geology, vol. 2, 1907, p. 398.

² Fuchs, Edmond, Note sur les gisements de cuivre du Boléo: Compt. rend. 14^e sess. Assoc. franç. avancem. sci. (Grenoble, 1886), pt. 2, 1886, pp. 410-426.

³ Stevens, H. J., The copper handbook, vol. 9, 1909, p. 889.

⁴ Quoted by Weed, W. H., The copper mines of the world, New York, 1907, pp. 245-246.

⁵ Idem, p. 246.

⁶ Yeatman, Pope, The Braden copper mines: Min. and Sci. Press, vol. 103, 1911, pp. 769-772.

chalcopyrite, bornite, secondary chalcopyrite, zinc blende, and tetrahedrite(?). The nonmetallic minerals include tourmaline, quartz, ankerite, calcite, chlorite, sericite, mica, epidote, and zircon. In the zone of oxidation are limonite, cuprite, native copper, and carbonates and silicates of copper.

In one ore body, in the Fortuna mine, chalcocite occurs apparently only on their coatings on pyrite and chalcopyrite, increasing the grade of the ore only slightly. In the Teniente ore body the effects of sulphide enrichment appear to be somewhat greater. It is concluded, however, that the copper content is mainly in the primary minerals. Over 10,000,000 tons of ore have been developed, the value being about 2.8 per cent copper.

QUEEN OF BRONZE MINE, OREGON.

The deposits of the Queen of Bronze mine, in southwestern Oregon,¹ are irregular masses of ore in fractured and fissured portions of gabbro, peridotite, and serpentine.

The unoxidized ore is chalcopyrite, with which are associated pyrite, pyrrhotite, and subordinate amounts of quartz and calcite. In the low-grade ores pyrite and pyrrhotite are the most abundant minerals. In addition to the copper content, the ores carry some gold and silver.

The oxidized ores are malachite, azurite, cuprite, tenorite(?), and chrysocolla. Of these the black ores containing tenorite or chalcocite are more abundant. The average content in copper was more than 10 per cent. The lower limit of the oxidized ores is usually less than 90 feet from the surface, but some have been found at greater depths. In a small opening about 105 feet below the surface black oxide and small amounts of native copper were observed.

Although depths of about 300 feet have been reached in the workings, no important body of ore has been found below 125 feet.

ENCAMPMENT DISTRICT, WYOMING.

The copper deposits of the Encampment district, Wyoming,² are in an area of pre-Cambrian metamorphosed igneous and sedimentary rocks, which are cut by pre-Cambrian gabbro, granite, and quartz diorite. The principal mines are the Doane and the Ferris-Haggarty, both of them in fractured quartzite. The primary copper ores are chalcopyrite and pyrrhotite. The secondary ores include azurite, malachite, chrysocolla, bornite, chalcocite, and covellite.

The country is about 10,000 feet above the sea; the climate is moist and ground water is near the surface. The lodes are tight and some mines are dry 450 feet below the surface.³ At the Ferris-Haggarty mine there was a strong capping of spongy limonite containing no visible copper minerals. At the Doane mine green copper minerals

¹ Diller, J. S., and Kay, G. F., Mineral resources of the Grants Pass quadrangle and bordering districts, Oregon: Bull. U. S. Geol. Survey No. 380, 1909, pp. 76-78.

² Spencer, A. C., The copper deposits of the Encampment district, Wyoming: Prof. Paper U. S. Geol. Survey No. 25, 1904.

³ Idem, p. 44.

mixed with the limonite were encountered at the surface and continued to a depth of 100 feet or more.¹

The richest ores occur immediately below the gossan and are composed chiefly of secondary chalcocite.² From the position of the stopes in several mine sections some chalcocite appears to extend downward probably 200 feet or more below the top of the chalcocite zone. The secondary copper ores, according to Graton,³ carried good values in precious metal.

DUCKTOWN, TENNESSEE.

The Ducktown district, in Tennessee, occupies an intermontane basin in the heart of the southern Appalachian region, near the Georgia-North Carolina boundary. The ore deposits outcrop between 1,400 and 1,800 feet above the sea. The climate is moist. The prevailing rocks of the district are sandy schists and graywackes, with which are interbedded mica schists. The dominant series is the metamorphosed product of an association of sedimentary beds, including conglomerate, grits, sandstones, and shales. The beds grade into one another along the strike and across the bedding. They contain small bodies of pegmatites and peculiar masses and stringers of an actinolite-feldspar rock which has a composition near that of quartz diorite. The schists are cut by dikes of gabbro, which are not so highly metamorphosed by pressure as the sedimentary beds. The schistosity and the bedding of the sedimentary rocks strike nearly everywhere northeast, and the prevailing dip is southeast. These rocks have been folded into sharp folds, many of them isoclinal. Many of the folds were broken along the crests of anticlines⁴ and pass into reverse strike faults that nearly everywhere dip southeast.

The ore bodies⁵ are replacements of limestone lenses which probably, though not certainly, were deposited at a single stratigraphic horizon. They range in width from a few feet to over 250 feet and have shapes that are characteristic of closely folded sedimentary beds. Anticlines and faulted anticlines, which are characteristic of this region, are shown in the ore zone. The ores themselves are somewhat metamorphosed by dynamic processes, and the gangue minerals are bent and twisted, but at most places they do not exhibit a well-defined

¹ Spencer, A. C., The copper deposits of the Encampment district, Wyoming: Prof. Paper U. S. Geol. Survey No. 25, 1904, p. 45.

² Idem, p. 55.

³ Graton, L. C., Mineral Resources U. S. for 1906, U. S. Geol. Survey, 1907, p. 410.

⁴ Keith, Arthur, Nantahala folio (No. 143), Geol. Atlas U. S., U. S. Geol. Survey, 1907.

⁵ Safford, J. M., Geology of Tennessee, Nashville, 1869, pp. 469-482. Whitney, J. D., Remarks on * * * the east Tennessee copper mines: Am. Jour. Sci., 2d ser., vol. 20, 1855, pp. 53-57. Ansted, D. T., On the copper lodes of Ducktown, in east Tennessee: Quart. Jour. Geol. Soc., vol. 13, 1857, pp. 245-254. Heinrich, Carl, The Ducktown ore deposits: Trans. Am. Inst. Min. Eng., vol. 25, 1896, p. 173. Kemp, J. F., The deposits of copper ores at Ducktown, Tenn.: Trans. Am. Inst. Min. Eng., vol. 31, 1902, pp. 244-265. Weed, W. H., Types of copper deposits in the southern United States: Trans. Am. Inst. Min. Eng., vol. 30, 1901, p. 480. Emmons, W. H., and Laney, F. B., Preliminary report on the mineral deposits of Ducktown, Tenn.: Bull. U. S. Geol. Survey No. 470, 1911, pp. 151-172.

schistosity. They were probably deposited after the rock that now incloses them and the limestone they replace had been subjected to considerable dynamic metamorphism. The outcrops are composed of iron oxides and quartz and contrast strongly with the country rock. All the lodes have a general northeast strike. South of the Culchote mine, which is near the center of the productive area, they strike more nearly north than east; north of the Culchote they strike more nearly east than north. In general the lodes dip southeast, but some dip northwest. The deepest development underground is about 800 feet below the surface.

The primary ore consists of pyrrhotite, pyrite, chalcopyrite, zinc blende, bornite, specularite, magnetite, actinolite, calcite, tremolite, quartz, pyroxene, garnet, zoisite, chlorite, micas, graphite, titanite, and feldspars. The minerals are generally intergrown and are of contemporaneous age. Essentially the same minerals are found in all the deposits, but they appear in varying proportions at different places in the lodes. Where its content of copper is above 1.5 per cent, or where its sulphur content is high, the material is ore, but where the proportion of actinolite and other lime silicates is greater and the sulphides are less abundant the material, though containing copper and other sulphides, is not workable.

The gossan extends from the surface to a maximum depth of 100 feet. It carries 40 to 50 per cent iron, generally less than 12 per cent silica and alumina, and 0.3 to 0.7 per cent copper. The minerals are hydrous iron oxides, quartz, jasper, and kaolin, with a little cuprite, native copper, and sulphur. Below the gossan iron ores is a zone of dark, rich copper ores, consisting of chalcocite and other copper minerals in a gangue of sulphates, quartz, and decomposed silicates. Under the higher portions of the outcrops of the lodes the top of this zone is about 100 feet below the surface, but the depth decreases down the slopes, and where the lodes are crossed by running streams the secondary copper ores are exposed at the surface. The upper limit of the chalcocite zone follows the level of ground water, which in turn follows the contour of the country but is less accentuated.¹

The secondary minerals include argentite, azurite, bornite, chalcanthite, chalcedony, chalcocite, chalcopyrite, chrysocolla, covellite, cuprite, gypsum, iron sulphate, jasper, kaolin, limonite, malachite, marcasite, melaconite, native copper, sulphur, and talc. The copper content of much of this ore ranges from 20 to 30 per cent.

The secondary zone is less extensive vertically than most chalcocite zones elsewhere. The lodes are comparatively impervious to downward circulation, and it is believed that the reactions were brought nearly to completion before the descending oxidized solutions had moved downward great distances.²

¹Emmons, W. H., and Laney, F. B., *op. cit.*, p. 170.

²Idem, p. 172.

In all the mines except the East Tennessee pyrrhotite is abundant, constituting more than half of the primary ore, and the vertical extent of the chalcocite zone is generally less than 10 feet. In the East Tennessee mine, in which pyrrhotite is much less abundant, the vertical extent of the chalcocite zone is at least 125 feet. The lodes are tight, and the downward circulation was probably slow before the mines were opened, but secondary chalcopyrite has been deposited below the chalcocite zone and probably extends 300 or 400 feet or more below the horizon of chalcocite.

GOSSAN LEAD, VIRGINIA.

The Gossan lead, in southwestern Virginia, is inclosed in highly metamorphosed crystalline schists. It strikes northeast, dips about 45° , and may be traced almost continuously for 18 miles. It consists of pyrrhotite, chalcopyrite, quartz, hornblende, mica, and other minerals.

Beneath the gossan there is usually found from a foot to 6 feet of the secondary copper ores, containing near the top more or less carbonate and oxide and very rarely a little native copper; farther down, on top of the unaltered sulphides, there is more or less soft black ore, the so-called "smut ore" of the miners, with secondary chalcopyrite.¹

As stated by Weed,² there has been some postmineral fracturing, which, presumably, would favor a downward circulation. The character of the enrichment is nevertheless closely similar to that in the pyrrhotite ores at Ducktown, Tenn. As stated by Watson,³ the weathering measured in 20 operations has extended to an average depth of 34 feet, ranging from 10 to 60 feet.

STONE HILL, ALABAMA.

At Stone Hill, Cleburne County, Ala., a deposit of pyrrhotite, with some chalcopyrite, is inclosed in gneiss and hornblendic and other schists. The ore body is said to be 24 feet wide and is traceable on the surface for 1,200 feet.⁴

Below the shallow gossan are rich "black copper" ores of rather slight vertical extent, above the yellow sulphides.

ELY, VERMONT.

The copper deposits near Ely, Vt., are lenticular masses in mica schist.⁵ Some of the deposits have been worked to very great depths. The ore is composed of pyrrhotite, scattered grains and irregular

¹ Weed, W. H., *Copper deposits of the Appalachian States*: Bull. U. S. Geol. Survey No. 455, 1911, p. 120.

² Idem, p. 119.

³ Watson, T. L., *Mineral resources of Virginia*, Lynchburg, 1907, p. 421.

⁴ Weed, W. H., *The copper mines of the world*, New York, 1907, p. 275.

⁵ Smyth, H. L., and Smith, P. S., *The copper deposits of Orange County, Vt.*: Eng. and Min. Jour., vol. 77, 1904, pp. 677-678. Weed, W. H., *Notes on the copper mines of Vermont*: Bull. U. S. Geol. Survey No. 226, 1904, p. 190.

masses of chalcopyrite, and small amounts of pyrite and zinc blende. The gangue minerals consist of quartz, actinolite, garnet, and other metamorphic minerals. The main part of the ore body consists of very massive pyrrhotite, with small amounts of quartz and other minerals.¹

The country has been glaciated, and the tops of the deposits have very little gossan, the sulphide appearing at some places at the surface. The richer ores near the surface of these deposits were removed long ago, and published descriptions of the details of their occurrence are not available to me. Mr. J. W. Tyson, of the Tennessee Copper Co., at Ducktown, who was present when some of these deposits were opened, informs me that the richer black ores were found within 100 feet of the surface and laid like a floor over the lower-grade yellow sulphides. The relations, he states, were closely similar to those of the "black ores" at Ducktown.

LA DICHA, MEXICO.

The Dicha mine, Guerrero, Mexico, is 150 miles south of the City of Mexico, in a mountainous country about 50 miles east of Acapulco. According to Weed,² the ore body, which occurs in micaceous schist, is parallel to the schistosity. It is proved for 7,700 feet along the strike and is from 12 to 88 feet wide. The ore consists of pyrrhotite with streaks, bunches, and specks of chalcopyrite scattered through it. It is said that the primary ore carries 5 per cent copper. Mr. Robert T. Hill³ informs me that the chalcocite zone is encountered at very shallow depths and is itself very thin, ranging in thickness from 6 inches to 6 feet. Its contact with pyrrhotite is sharp.

SANTIAGO, CUBA.

Copper lodes are found at several places along the south coast of Cuba east and west of Santiago. The most important deposits are those of the El Cobre mine. The ore minerals of the veins include pyrite, chalcopyrite, pyrrhotite, and quartz.⁴ Oxidized and chalcocite ores were found 50 or 60 feet below the outcrop. At greater depths pyritic ores in a siliceous gangue were found to carry 6 per cent copper without precious metals in paying quantity. The old workings, now caved, extended 1,300 feet below the surface. Copper is precipitated from mine waters on scrap iron.

¹ Weed, W. H., *op. cit.*, pp. 192-193.

² Weed, W. H. (quoting R. T. Hill), *The copper mines of the world*, New York, 1907, p. 251.

³ Correspondence.

⁴ Lawrence, B. B., *Copper mining in Cuba: Min. and Sci. Press*, vol. 98, 1906, p. 602. Weed, W. H., *The copper mines of the world*, New York, 1907, p. 200.

PINAR DEL RIO, CUBA.

In the Province of Pinar del Rio, at the extreme west end of Cuba, gossans 150 to 200 feet wide are found. Below the gossans, at depths of 40 to 50 feet, are black copper ores. The sulphides include pyrrhotite, chalcopyrite, and chalcocite.¹ The relations, according to Benjamin B. Lawrence, are similar in some respects to those seen at Ducktown, Tenn.

BOUNDARY DISTRICT, BRITISH COLUMBIA.

The Boundary district, British Columbia,² lies between Columbia and Okanogan rivers, near the international boundary. The country is mountainous, forested, and about 5,000 feet above sea level. It is an area of sedimentary rocks, including limestones, argillites, and quartzite, with volcanic tuffs and ash beds, probably of Paleozoic age. Associated with these rocks are gneisses and schists, possibly Paleozoic also. The later rocks are porphyries, serpentines, and granodiorite. Various intrusions and flows of andesite, basalt, and other rocks are probably Tertiary. The deposits are perhaps related to intrusions of alkali syenite, which cuts most of the other rocks and is of Tertiary age.

The principal deposits are in limestone or greenstone, not far from intruding masses. The gangue minerals, according to Brock, include garnet, epidote, calcite, quartz, and actinolite. The principal sulphides are pyrite, chalcopyrite, and pyrrhotite. Magnetite is abundant in some deposits, and these contain less of the iron sulphides. Sphalerite, galena, and arsenopyrite are also present, and the ores contain appreciable quantities of gold and silver.

Oxidation extends only a few feet down into the copper ores, and locally the sulphide ore is polished and striated by ice.

The mother lode, according to Brock, is over 100 feet wide and at least 1,180 feet long and is developed to a depth of about 500 feet. Chalcocite is practically unknown in this deposit, the principal copper mineral being chalcopyrite. It is reported that the valuable minerals decrease in amount with increase of depth, but it is not certain that the richer deposits near the surface are due to chalcopyrite enrichment. A lens of the Knobhill-Ironsides deposit, according to Le Roy,³ is nearly half a mile long and has a maximum thickness of 125 feet and a known maximum width of 900 feet. Pay ore, according to Stevens, does not extend below 400 feet. Stevens says that the values

¹ Lawrence, B. B., *Copper mining in Cuba*: Min. and Sci. Press, vol. 93, 1906, p. 602.

² Brock, R. W., *Preliminary report on the Boundary Creek district, British Columbia*: Summ. Rept. Geol. Survey Canada for 1902, 1903, pp. 90-136. Le Roy, O. E., *The geology and ore deposits of Phoenix, Boundary district, British Columbia*: Mem. Geol. Survey Canada No. 21, 1912. Stevens, H. J., *The copper handbook*, vol. 9, 1909, pp. 206-207. Ledoux, A. R., *The production of copper in the Boundary district, British Columbia*: Jour. Canadian Min. Inst., vol. 5, 1902, pp. 171-177.

³ Le Roy, O. E., *op. cit.*, p. 57.

have declined from 1.7 per cent copper, 0.5 ounce silver, and \$2 gold per ton to about 40 per cent less in copper, 50 per cent in silver, and 60 per cent in gold. The ore reserves in 1910 were estimated by Otto Sussman at 5,595,000 tons.

At Copper Camp, near the head of Copper Creek, oxidized deposits of copper ores are found. In depth these give way to secondary sulphides, including chalcocite, below which are pyrite and chalcopyrite.

On the margins of the principal copper deposits are gold and silver veins. The minerals of these deposits include chalcocite, galena, zinc blende, pyrite, chalcopyrite, ruby silver, argentite, native silver, and gold. The chalcocite, rich silver minerals, and native silver and gold usually occur, it is said, in films around quartz crystals or in small crevices in quartz and calcite, indicating that they are products of enrichment.

SAN JOSE, MEXICO.

San Jose, Tamaulipas, Mexico, is 40 miles from Linares, on the Monterey & Mexican Gulf Railway. The principal productive area is about 2,250 feet above sea level. The deposits are in an area of limestone and nepheline syenite, and the limestone is intruded by diorite and by porphyry.¹

The limestone and the porphyry are cut by tinguaites and by basic dikes. Typical zones of heavy silicates with sulphide copper ores are developed near contacts of limestone and diorite porphyry.² Magnetite is a contact mineral and is locally developed in large irregular masses. On the borders there are intermingled garnet and diopside, and throughout the magnetite are abundant veinlets of chalcopyrite and pyrite. One prominent outcrop gave the name "Piedra Imán," or lodestone, to the summit of Remedios Hill.

The most important copper mineral is chalcopyrite, which, according to Kemp, is almost invariably associated with pyrite. They appear not only as inclusions in the silicates but also as veinlets and as coatings in cavities. They cover in places the well-developed crystals of garnet so as to mold around them like a paste. The sulphides may themselves form large masses analogous to the magnetite and thus yield the best stopes of ore.

Ores including malachite, chrysocolla, and subordinate cuprite are found in the oxidized zone, especially along faults. I can find no mention of chalcocite in Kemp's descriptions.

¹ Finlay, G. I., The geology of the San Jose district, Tamaulipas, Mexico: *Annals New York Acad. Sci.*, vol. 14, 1904, pp. 247-295. Kemp, J. F., The copper deposits at San Jose, Tamaulipas, Mexico: *Trans. Am. Inst. Min. Eng.*, vol. 36, 1906, pp. 178-203.

² Kemp, J. F., *op. cit.*, p. 189.

LA REFORMA MINE, CAMPO MORADO, MEXICO.

The Reforma mine at Campo Morado, Guerrero, Mexico, is in an area of somewhat metamorphosed sedimentary rocks (probably Lower Cretaceous) that are cut by granodiorite, which locally is sheared. Later porphyry, probably monzonite porphyry, intrudes the older rock.

The ore bodies, as stated by J. W. Finch,¹ are large and are extensively developed. The sulphide ore consists of practically solid masses of pyrite, with chalcopyrite, sphalerite, and galena and little or no quartz. It fills and replaces the beds, usually along the contacts with granodiorite, but is thought to be genetically related to the late intrusions. The Reforma body has an average width in six levels of about 100 feet and is continuous through the mountain. On the sixth level pyrite is developed for 2,000 feet on the strike between the oxidized zone at each end of the level.

The values are about equally distributed between gold, silver, and copper. The pyritic mass is compact and offers no large channels for water circulation. Oxidation is apparently thorough above the water level, but there has been very little reconcentration of copper in the oxidized zone. The copper-bearing waters appear to have drained laterally along the strike in the gossan to the surface or through the footwall slates. The zone of attack of oxidizing agents, as stated by Finch, appears to be measurable vertically in inches along practically all the profile of the pyrite, oxidation being complete as deep as it descends. A little covellite was found at the top of the pyrite in the Navajo workings, near by, but neither covellite nor chalcocite has been recognized in the Reforma. The sulphides appear to be impervious, and there is no evidence whatever of sulphide enrichment.

VELARDEÑA DISTRICT, MEXICO.

The Velardeña district, Durango, Mexico,² near the Mexican International Railroad, between Torreon and Durango, is an area of folded Mesozoic (probably Cretaceous) limestone which is covered with andesitic tuffs and flows and cut by andesite intrusions. Dikes and irregular masses of alaskite and of trachytic alaskite and diorite intrude the older rocks. A siliceous phase of the diorite, probably quartz monzonite, is limited to a single intrusion near the Copper Queen mine. Contact metamorphism, with the development of heavy silicates and metallic sulphides, has attended the intrusion of several of these rocks, and an interesting feature is the metamorphism and development of heavy silicates in igneous as well as in calcareous

¹ Finch, J. W., *A geological journey in Guerrero: Min. and Sci. Press*, vol. 101, 1910, p. 498.

² Spurr, J. E., and Garrey, G. H., *Ore deposits of the Velardeña district, Mexico: Econ. Geology*, vol. 3, 1908, pp. 688-725.

sedimentary rocks. The ore deposits are of varied character and clearly indicate several epochs of ore deposition.

The deposits differ greatly in mineral composition, but most of them contain considerable zinc blende, zinc being about as abundant as copper. Some deposits contain also pyrrhotite.

The Copper Queen ore body, containing the principal copper ore of the region, consists of three main pipes or chimneys in metamorphic rock at the contact of the Copper Queen intrusion. The principal sulphides are slightly cupiferous pyrite, blende, and galena. The ores here mined are primary and there is no very great change of nature in depth.¹

SUDBURY, ONTARIO.

The Sudbury nickel region, Ontario,² is in a hilly, glaciated country of moderate relief. The climate is cold and moist. The nickeliferous rocks are included in an elliptical area some 40 miles long and 20 miles wide, the longer axis striking north of east. The central portion of the ellipse, occupied by Upper Huronian or post-Huronian rocks, has been weathered to a peneplain, which is surrounded by a hilly belt of eruptive rock. The oldest series in the region consists of Huronian graywacke, slate, quartzite, and conglomerate, which are intruded by acidic and basic eruptives.³ The Upper Huronian rocks (Animikie group) include conglomerate, tuffs, slates, and sandstones. Intruded between the Lower Huronian rocks or their igneous intrusives and the Upper Huronian sedimentary rocks is the great laccolithic mass, or sheet, probably of Keeweenawan age, which constitutes the Sudbury nickel-bearing eruptive. This great sheet dips toward its center, forming a canoe-shaped body which outcrops in a rudely elliptical belt having a nearly plane surface. As a result of magmatic differentiation the lower portion of the eruptive is norite and the upper portion is micropegmatite, the two rocks grading into each other.

The ore deposits are (1) magmatic segregations, which occur between the norite and the underlying rocks, especially in depressions in the Huronian or in rocks intruded in the Huronian; (2) deposits of nearly related genesis in or near dikes of norite that extend outward from the lower contact of the main laccolithic body; and (3) deposits outside the laccolith, associated with norite intrusions, which possibly are connected with the principal body of the nickeliferous eruptive beneath the surface. The ore consists chiefly of pyrrhotite, which contains a small amount of pentlandite and

¹ Spurr, J. E., and Garrey, G. H., Ore deposits of the Velardeña district, Mexico: *Econ. Geology*, vol. 3, 1908, p. 719.

² Barlow, A. E., Report on the origin, geological relations, and composition of the nickel and copper deposits of the Sudbury mining district, Ontario: *Ann. Rept. Geol. Survey Canada*, vol. 14, pt. H, 1904. Coleman, A. P., The Sudbury nickel field: *Rept. Ontario Bur. Mines*, vol. 14, pt. 3, 1905, p. 14.

³ Coleman, A. P., *loc. cit.*

chalcopyrite. At many places it grades imperceptibly into pyrrhotitic norite. Fissures in the eruptive rock are filled with quartz and sulphides, and along the contact with the older rocks sulphides have been deposited by contact-metamorphic processes. Pyrite is intimately associated with pyrrhotite.¹ Other minerals are magnetite, niccolite, cassiterite, gersdorffite, polydymite, danite, galena, native copper, sperrylite, and gold. The gangue includes the rock-making minerals of norite, with some quartz, calcite, and other carbonates. Alteration products include limonite, chalcocite, bornite, morenosite, annabergite, millerite, and probably several other species.

Rounded hills of gossan,² indicating the presence of sulphide ore beneath, extend with almost unbroken continuity for miles along the contact of norite with underlying rocks. The offsets and isolated masses of norite with which some of the ore bodies are associated are generally made brownish by the decomposition of disseminated sulphides. Locally the covering of gossan is as much as 6 feet deep, although its ordinary depth is 2 or 3 feet, and it merges into sulphide ore beneath. Chalcocite ores are not conspicuously developed, although the presence of chalcocite in some deposits is noted by both Barlow and Coleman. In the Vermilion mine, where the gossan is deepest, chalcocite and copper carbonate are developed and there is a concentration of platinum or sperrylite in the gossan. The relations at the Copper Cliff mine of the Canadian Copper Co. suggest a probable chalcopyrite enrichment. In the earlier years of the development of this mine copper was greatly in excess of nickel, averaging 6.44 per cent, while nickel averaged only 2.38 per cent. Subsequently their proportions were reversed, and in 1904³ the matte from this deposit contained nearly twice as much nickel as copper. Of sulphide enrichment, C. W. Dickson⁴ says that it is possible that the copper disseminated in the upper part of the ore bodies, now eroded, has been secondarily deposited by downward-moving currents, but apparently not to any great extent, for the ground-water level is comparatively near the surface and there is little if any enriched sulphide.

When the thin surface covering is removed the pyrrhotite appears perfectly fresh and is without appreciable admixture of secondary minerals, such as are formed in the process of enrichment.

¹ Barlow, A. E., *op. cit.*, p. 97.

² *Idem*, p. 121.

³ *Idem*, p. 110.

⁴ Dickson, C. W., *The ore deposits of Sudbury, Ontario: Trans. Am. Inst. Min. Eng.*, vol. 34, 1904, pp. 61-62.

PRINCE WILLIAM SOUND, ALASKA.

The deposits of Prince William Sound, Alaska, are in graywacke and slates¹ of two unconformable series, closely folded but not highly metamorphosed. These are cut by granites, acidic dike rocks, and basic intrusive rocks. Basic flows altered to greenstone are commonly interstratified with the sedimentary rocks. The ores were deposited in zones of fracturing and shearing. The minerals in the ore bodies are chiefly pyrrhotite and chalcopyrite. With these in places are quartz, pyrite, and sphalerite, and at least one vein contains magnetite. As a rule the ore minerals are intimately intergrown and are thus apparently of contemporaneous origin.²

Possibly extensive surface alteration and sulphide enrichment took place before glaciation, and the remnants of the workable ores may be the roots of such enriched deposits. In the Bonanza mine, Latouche Island, chalcopyrite is less abundant in the lower level than it is nearer the surface. Since glaciation occurred there has been surface leaching and probably enrichment of the deposit, as is shown (1) by gossan, a few feet thick; (2) by a zone of black sulphides, a few inches thick, above the main ore; and (3) by waters that are carrying copper in solution and are in one locality depositing native copper and malachite.³

According to F. C. Lincoln³ the leachings from glacial boulders have been precipitated in crevices as malachite.

KASAAN PENINSULA, PRINCE OF WALES ISLAND, ALASKA.

The copper deposits of Kasaan Peninsula⁴ are in an area of calcareous and other sedimentary rocks, which are interbedded with volcanic tuffs and cut by intruding masses of granodiorite and dikes of granite, syenite, and pegmatite. These intrusions were followed by the intrusion of dikes of felsite and subsequently of small dikes of diabase and basalt, which cut the ore bodies. The sedimentary rocks are greatly metamorphosed near their contact with the intruding rocks, where typical garnet-epidote-magnetite contact zones are developed. The deposits are in the main iron-copper sulphides, intergrown with the garnet gangue, and are generally near the contact of the sedimentary rocks with intrusive syenite. Most of the deposits are worked by open pits.

The ore is composed largely of magnetite, chalcopyrite, and pyrite associated with hornblende and calcite, all of which are included in a more or less banded garnet-epidote gangue.

¹ Grant, U. S., and Higgins, D. F., Reconnaissance of the geology and mineral resources of Prince William Sound, Alaska: Bull. U. S. Geol. Survey No. 443, 1910, p. 20.

² Idem, p. 58.

³ Lincoln, F. C., The Big Bonanza copper mine, Latouche Island, Alaska: Econ. Geology, vol. 4, 1909, p. 212.

⁴ Wright, C. W., and Paige, Sidney, Copper deposits on Kasaan Peninsula, Prince of Wales Island: Bull. U. S. Geol. Survey No. 345, 1908, p. 98. Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: Bull. U. S. Geol. Survey No. 347, 1908.

Surface oxidation has produced considerable limonite and some malachite and azurite; small particles of native copper also occur along slipping planes. These secondary minerals are relatively unimportant.¹

It appears from descriptions of the various mines by Wright and Paige that pyrrhotite and zinc blende are lacking or very subordinate in these deposits. Pyrrhotite occurs in two of the prospects and in one of these zinc blende is present in considerable amount. Chalcocite enrichment is practically absent, though some was noted on the Goodro claims 200 feet below the surface. In the short time since the glacial epoch the pyrite and chalcopyrite have precipitated practically no secondary copper, though some oxidation has taken place and in a mine at Copper Mountain carbonates were noted 300 feet below the surface.²

BONANZA MINE, CHITINA COPPER BELT, ALASKA.

The Chitina copper belt, Alaska,³ is an area of greenstone, mainly diabase, which is overlain by Triassic limestones. Above the limestones are later sedimentary rocks. The various rocks are cut by porphyries, diorites, and gabbros. Andesite and other volcanic rocks, probably of Tertiary age, are also present. The country is rugged and the region of the deposits has been deeply eroded. The principal deposit is a rudely tabular mass of nearly pure chalcocite, which occurs in a fractured or fissured zone in the limestone just above the contact with greenstone. The very rich ore can be traced on the surface for about 250 feet. The deposit carries more than 60 per cent copper and 22 ounces silver to the ton and is estimated to contain over 100,000,000 pounds of copper.⁴ The thickness is indefinite, but the very rich ore, with its included limestone, as seen at the surface, has a width of approximately 25 feet, although the thickness of ore sufficiently rich to be mined may be greater. Below the deposit a little chalcocite and less bornite are found in some of the shearing planes in the greenstone but do not extend far into the greenstone. The quantity of each is small and the minerals are inconspicuous and might readily pass unobserved. A small amount of epidote is in places associated with the chalcocite.⁵

Though it extends to the very surface and accumulates in talus from the cliff, the chalcocite ore has no great vertical range. Owing to the rapid mechanical disintegration and the cold climate little or no gossan is developed. Open cavities in the fractured limestone have been filled with ice, and both the country rock and the talus on either

¹ Wright, C. W., and Paige, Sidney, *op. cit.*, p. 105.

² Wright, C. W., *Prospecting in the North* (discussion): *Min. Mag.*, vol. 4, 1911, p. 359.

³ Moffit, F. H., and Maddren, A. G., *Mineral resources of the Kotsina-Chitina region, Alaska*: *Bull. U. S. Geol. Survey* No. 374, 1909, p. 80.

⁴ Graton, L. C., *Mineral Resources U. S. for 1907*, pt. 1, U. S. Geol. Survey, 1908, p. 592.

⁵ Moffit, F. H., and Maddren, A. G., *op. cit.*, p. 83.

side of this ridge are frozen all summer except for a few feet at the surface. No chalcopyrite and pyrite are recognized in the chalcocite ore. There is no evidence that either of these minerals was replaced, but immediately below the contact in the same shear zone bornite, chalcocite, and native copper are present in small amounts.¹

It seems most unlikely that pyrite and chalcopyrite would be so completely replaced as to leave no vestige of the original mineral. Organic matter, especially if supplying hydrogen sulphide, could precipitate the copper as chalcocite, and the character and purity of the glance suggests a genesis somewhat similar to that of the copper glance deposits of Cashin, Colo., or the replacements of coaly material in many prospects in the West.²

In this connection the following statement of Moffit and Maddren³ is suggestive: The limestone "is found to have a blue color, which is indicative of considerable carbonaceous material in its composition." Although Moffit and Maddren only state alternate hypotheses as to the mode of deposition of the ore, in their discussion of the subject they seem clearly to favor the one which suggests the agency of cold waters. A possible source of the copper is the greenstone upon which the limestone rests. This formation is mainly diabase and at many places it carries a little copper.

MOTHER LODE DISTRICT, CALIFORNIA.

The Mother Lode district, California, as described by Ransome,⁴ is an area of crystalline schists and altered igneous rocks with intruded granodiorite and related rocks. The deposits are fissure veins, which generally trend northwestward and at many places parallel the schistosity of the country rock. I have no record that the ores contain manganese minerals. Placers are abundantly developed, and at many places rich ore is found at the very surface. According to Ransome, there is no evidence that the mines grow suddenly richer at any particular depth, nor is there any recognizable regular change in the value of pay shoots with depth below the zone of superficial weathering. Some of these deposits are very regular and uniform in value and have been developed to very great depths.

NEVADA CITY AND GRASS VALLEY, CALIFORNIA.

The area of Nevada City and Grass Valley, Cal.,⁵ includes metamorphosed Carboniferous sedimentary rocks, compressed into isoclinal, and associated igneous rocks less intensely metamorphosed. Above

¹ Moffit, F. H., and Maddren, A. G., op. cit., p. 53.

² Lindgren, Waldemar, Copper, silver, lead, vanadium, and uranium ores in sandstone and shale: *Econ. Geology*, vol. 6, 1911, p. 568.

³ Moffit, F. H., and Maddren, A. G., op. cit., p. 25.

⁴ Ransome, F. L., Mother Lode district folio (No. 63), *Geol. Atlas U. S.*, U. S. Geol. Survey, 1900, p. 3.

⁵ Lindgren, Waldemar, The gold-quartz veins of Nevada City and Grass Valley districts, California: *Seventeenth Ann. Rept. U. S. Geol. Survey*, pt. 2, 1896, pp. 1-262.

these are slates with associated diabase and serpentine. These rocks are folded and metamorphosed but are not so intensely compressed as the Carboniferous. Intruded into these rocks are great bodies of granodiorite, probably of early Cretaceous age. The ore deposits are strong fissure veins, formed after the granodiorite intrusions. The minerals are quartz, chalcedony, magnetite, sericite, mariposite, pyrite, pyrrhotite, chalcopyrite, galena, blende, scheelite, arsenopyrite, tetrahedrite, stephanite, and cinnabar. Some earthy manganese ore occurs in small fissures in the granodiorite but not in connection with the quartz veins.

Near the surface¹ the upper part of a vein is generally decomposed, forming a mass of limonite and quartz. The decomposition seldom extends more than 200 feet on the incline of a vein dipping 45°, or more than 150 feet below the surface. Fresh ore is found in places almost at the surface. The surface ore is generally richer than the fresh ore below, owing to the liberation of gold from the sulphides and the removal of substances other than gold. In this process silver also is partly removed. In some of the mines the lodes have been followed down the dip for 2,000 or even 3,000 feet. The unoxidized ore shows no gradual diminution of tenor in the pay shoots below the zone of surface decomposition. Within the same shoot there may be great variations of the tenor, but there is certainly no gradual decrease of it from the surface down. Important placer deposits were formed from these veins.

OPHIR, CALIFORNIA.

The rocks of the Ophir district, California,² comprise amphibolite schists and massive amphibolites, with intrusions of granodiorite. These rocks are cut by quartz veins which fill coordinate fissures. The minerals are gold, electrum, some iron, copper and arsenical pyrites, with galena, zinc blende, tetrahedrite, and molybdenite. The gangue is mainly quartz, with a little calcite. The proportion of gold to silver varies by weight from 1:1 to 1:10, the gold predominating in value. Certain small ore shoots in veins in the amphibolite carry more than the usual tenor of gold, and the richest shoots are usually found where veins cross the belts rich in pyrite. According to Lindgren, such ore bodies may have been enriched by thermal waters concentrating gold from the pyrite in the iron belt. The common statement that the gold vein becomes barren as the depth from the surface increases is not justified, in his opinion,³ by the evidence afforded in the mines. The extensive development of placers, the value of

¹ Lindgren, Waldemar, *The gold-quartz veins of Nevada City and Grass Valley districts, California: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 182.*

² Lindgren, Waldemar, *The gold-silver veins of Ophir, Cal.: Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, p. 252.*

³ *Idem*, p. 279.

the ore near the surface, and the occurrence of valuable ore shoots just below the surface are opposed to the notion of extensive migration of gold in these deposits.

SILVER PEAK, NEVADA.

According to Spurr,¹ the deposits of Silver Peak, Nev., are lenticular masses and fissure veins in Paleozoic sedimentary rocks. Genetically they are related very closely to granitic rocks which, as shown by Spurr, have alaskitic or pegmatitic phases. They are probably post-Jurassic and should be grouped with the California gold veins, with which geologically they have much in common. Concerning the Drinkwater and Crowning Glory deposits, which are the most important examples, Spurr says that no decided enrichment of the ores by oxidation can be established. The ores in the upper tunnel seem to have been locally richer than any found in the lower tunnel, but this difference has no evident relation to the surface and is probably original. The values occur as finely disseminated gold and auriferous sulphides. Placers are not mentioned.

EDGEMONT, NEVADA.

The gold deposits at Edgemont, Elko County, Nev.,² are in an area of quartzite, with intrusions of granodiorite. The deposits are fissure veins and their gold values are comparatively uniform. The ore consists of pyrite, galena, and arsenopyrite in a gangue of quartz. Copper carbonates and manganese minerals are rare or absent. The ore is stoped practically to the surface. There has probably been a slight amount of enrichment by removal of certain substances in the oxidized zone more rapidly than gold; there is no evidence that gold has been transferred below the water level by descending surface waters.

DOUGLAS ISLAND, ALASKA.

At the Treadwell mines, Douglas Island, Alaska, large dikes of albite diorite intrude greenstones and schist, and the shattered diorite has been extensively replaced by mineralizing solutions and cemented by low-grade gold ore. The minerals include quartz, albite, rutile, chlorite, epidote, calcite, siderite, pyrite, pyrrhotite, magnetite, chalcopryite, and molybdenite. Manganese minerals are not reported.

The mines have been developed for 2,000 feet down the dip. According to Spencer,³ the ore shows no progressive change in appearance or value with increasing depth. In the lowest level it is quite as

¹ Spurr, J. E., Ore deposits of the Silver Peak quadrangle, Nevada: Prof. Paper U. S. Geol. Survey No. 55, 1906.

² Emmons, W. H., A reconnaissance of some mining camps in Elko, Lander, and Eureka counties, Nev.: Bull. U. S. Geol. Survey No. 408, 1910, pp. 75-80.

³ Spencer, A. C., The Juneau gold belt, Alaska: Bull. U. S. Geol. Survey No. 287, 1906, pp. 32, 115.

rich as in the upper workings, and it is evident that changes on the dip are no greater than along the strike. The best level of the Alaska Treadwell mine, according to Hershey,¹ is 1,300 feet below sea level. Nothing in the character of the ore indicates any important concentration of values by oxidizing waters. The fact that extensive placers were not formed is not opposed to the view expressed by Spencer that the gold has not been transferred; the country has been recently glaciated and surface accumulations have been scattered. The gold accumulated at the apex since glacial time was, indeed, recovered by sluicing.

BERNERS BAY REGION, ALASKA.

The Berners Bay region lies along the Lynn Canal, 45 miles northwest of Juneau, Alaska. The country is an area of slates and graywackes of Jurassic or Cretaceous age and basic lavas and quartz diorites considerably altered by dynamic metamorphism. The Jualin diorite, intruding the sediments and lavas, is also later than the metamorphosed quartz diorite.²

The gold deposits, which are mainly in the Jualin diorite, are stockworks and fissure veins. The ores are composed of quartz, some calcite and pyrite, and minor amounts of chalcopyrite, galena, and sphalerite. The alteration of the wall rock was attended by the production of albite. Evidence of enrichment is lacking.

Knopf³ says:

Any enriched surface ores that may have existed within this region have been swept away by the powerful glacial erosion to which the region was subjected in the recent geologic past. The ores exposed at the surface are therefore of primary origin, modified to an unimportant extent by postglacial oxidation, and the outcrop of any ore deposit will furnish a true index of the value of the lode as a whole, depending on whether the distribution of values in the ore is or is not uniform.

BLACK HILLS, SOUTH DAKOTA.

The principal gold deposits of the Black Hills⁴ are in pre-Cambrian schists which, like the ore bodies, are cut by Tertiary intrusives. Since the Cambrian conglomerates contain placer gold,⁵ some of the ores must have been deposited in pre-Cambrian time. The most important deposits are comprised in the Homestake belt, about 3 miles long and 2,000 feet wide. The principal minerals are quartz,

¹ Hershey, O. H., *Geology at Treadwell mines*: Min. and Sci. Press, vol. 102, 1911, pp. 296-300, 334-335; also in Bain, H. F. (ed.), *Types of ore deposits*, San Francisco, 1911, pp. 157-171.

² Knopf, Adolph, *Geology of the Berners Bay region, Alaska*: Bull. U. S. Geol. Survey No. 446, 1911.

³ Idem, p. 36.

⁴ Irving, J. D., *Economic resources of the northern Black Hills*: Prof. Paper U. S. Geol. Survey No. 26, 1904.

⁵ Devereux, W. B., *The occurrence of gold in the Potsdam formation, Black Hills, S. Dak.*: Trans. Am. Inst. Min. Eng., vol. 10, 1882, p. 469.

dolomite, calcite, pyrite, arsenopyrite, pyrrhotite,¹ and gold, with which are associated the minerals of the schist—quartz, orthoclase, hornblende, biotite, garnet, tremolite, actinolite, titanite, and graphite.² The ores, though uniformly of low grade, are very profitable. Some of the ores at the surface were below the average tenor, while other surface ores were two or three times as rich as the average. The valuable minerals extend downward as far as exploration has gone and are fairly uniform to 1,000 feet or more below the surface. In general, according to S. F. Emmons,³ enrichment by surface leaching has had relatively small importance.

HEDLEY DISTRICT, BRITISH COLUMBIA.

The Hedley district, British Columbia, is in the valley of Similkameen River, some 30 miles north of the international boundary. The principal deposits are about 5,000 feet above sea level, and the whole district was covered with ice in the glacial epoch. The oldest rocks⁴ are of Paleozoic age, probably Carboniferous, and consist of limestones, quartzites, and argillites, interbedded with which are subaqueous volcanic tuffs and breccias. These are intruded by Mesozoic diorite and gabbro, by Tertiary granodiorite, and by dikes of aplite, rhyolite, and andesite.

According to Camsell, the ore bodies are contact-metamorphic deposits, which occur mainly in limestone near intrusive diorite or gabbro. Metamorphism has been greatest along contacts with gabbro.⁵ The sulphides carry abundant arsenopyrite, with pyrrhotite, chalcopyrite, pyrite, and zinc blende; the gangue minerals include garnet, epidote, tremolite, diopside, and axinite, with some calcite and quartz. No manganese gangue mineral is mentioned and but small amounts are shown in analyses of the igneous rocks.

There is a thin capping of iron oxide, which extends in general some 8 or 10 feet below the surface. Leaching is deeper in ores composed chiefly of pyrrhotite than in ores composed mainly of arsenopyrite. There is no zone of enriched sulphides; but gold, which is the principal metal, has been transported downward to some extent, according to Camsell, resulting in an enrichment near the surface and to depths perhaps several hundred feet below. In ore bodies having a low dip there is a notable concentration of values along the gabbro footwall.

¹ Sharwood, W. J., *Analyses of some rocks and minerals from the Homestake mine, Lead, S. Dak.*: Econ. Geology, vol. 6, 1911.

² Irving, J. D., *op. cit.*, p. 90.

³ *Idem*, p. 79.

⁴ Camsell, Charles, *The geology and ore deposits of Hedley mining district, British Columbia*: Mem. Geol. Survey Canada No. 2, 1910.

⁵ *Idem*, p. 25.

APPALACHIAN DISTRICTS.

The gold deposits of the southern Appalachians are among the oldest gold deposits of the United States and were probably formed,¹ in the main, 3 or 4 miles below the surface at the time of deposition. Many of them are in mica schist and other crystalline rocks, and some are closely associated with granitic intrusions. Some are cut by diabasic intrusives, presumably later than the ore. The deposits have yielded considerable placer and lode gold. The minerals, according to Graton,² include quartz, sericite, biotite, fluorite, gold, pyrite, galena, blende, pyrrhotite, chalcopyrite, and magnetite. Manganese minerals are not mentioned. In Becker's tabulation of the minerals of the gold mines of the southern Appalachians, compiled from all previous descriptions and including some mines not described by Graton, pyrolusite is mentioned as occurring in only three mines and rhodochrosite in one.³

Few of these deposits have been extensively explored in depth, and data respecting the vertical distribution of the gold are therefore meager. Many of them are profitable near the surface, partly by reason of the rotten condition of the rock, which renders it more easily worked, and partly because gold is accumulated or enriched by the removal of valueless material. In general there is, according to Graton, very little evidence for or against the theory of the migration of gold; but such migration, if it has taken place, has been extremely slow, for areas which have probably been exposed since Tertiary time show a marked concentration at and near the surface. Possibly some gold has been transferred to lower levels at the Haile mine, South Carolina, where, according to Graton, the limit of profitable mining is in general less than 200 feet below the limit of complete oxidation. In this zone scales of pyrite and free gold are found in joint cracks, indicating a relatively recent age. The deposits are cut by basic dikes. Prior to Graton's work many thought that the primary deposition of gold was genetically related to the dikes,⁴ for the workable ore appears to be limited to the area cut by them. If the basic dikes (like most basic rocks) carry manganese, it would appear probable that gold had been dissolved and the ore enriched near the dikes. Graton's tables show zinc blende in but one mine, the Kings Mountain mine, and pyrrhotite in but three others, the Haile, the Colossus, and the Asbury (which is not described). Both minerals are in the ore of the Dahlonega district described by Lindgren.⁵ All

¹ Lindgren, Waldemar, The gold deposits of Dahlonega, Ga.: Bull. U. S. Geol. Survey No. 293, 1906, p. 124.

² Graton, L. C., Reconnaissance of some gold and tin deposits of the southern Appalachians: Idem, p. 62.

³ Becker, G. F., Reconnaissance of the gold fields of the southern Appalachians: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1895, p. 277.

⁴ Maclaren, J. M., Gold, its geological occurrence and geographical distribution, London, 1908, pp. 57, 59.

⁵ Lindgren, Waldemar, op. cit., p. 119.

these deposits had relatively rich ore near the surface and in none of them did it extend to great depths.

Certain ore deposits of Alabama recently described by McCaskey¹ comprise fissure veins in granite and lenticular bodies in schists. The principal minerals are quartz, pyrite, and gold. Some garnet is found in the vein quartz at Pinetuckey. Weathering extends to water level, which lies 40 to 80 feet below the surface. The ores are oxidized above this level and are generally free milling, but below this level the ore is not profitably amalgamated so far as explored in depth. The ores are fairly regular in width and values, and no evidences of enrichment below the water level are recorded.

ANNIE LAURIE MINE, UTAH.

The Annie Laurie mine,² 175 miles south of Salt Lake, Utah, is in an area of dacite, rhyolite, and rhyolite tuff and probably belongs to the later Tertiary group. The vein is poorly exposed at the surface, being largely covered by morainal material. Lindgren says:

The quartz forms an almost continuous sheet along the vein, rarely less than 3 feet in thickness and often expanding to a width of 20 feet or more. As a rule, the walls are poorly defined and slickensides indicating motion are rare. In places it contains, parallel to the walls, streaks of iron oxides and black, sooty manganese ores. * * *

The mine workings have not penetrated below the zone of oxidation, and neither the quartz nor the country rock seems to contain any unoxidized sulphides.

In the absence of extensive postmineral fracturing one would suppose that the conditions for migration of gold were not particularly favorable. Since the workings had not penetrated sulphide ore at the date of Lindgren's report, direct evidence was lacking.

MANHATTAN, NEVADA.

The gold deposits at Manhattan, Nev., although inclosed in schists, are in an area of Tertiary volcanic activity and should be classed with the deposits formed in Tertiary time. Although the schists contain stringers of gold of uncertain genesis, the principal deposits are steeply dipping lodes of quartz and calcite, stained with iron and manganese oxides. Some placers are developed. Rich ore was found very near the surface, but it was richer a few feet below the outcrop than at the surface. Some fracturing has taken place since the deposits were formed. The gold of many of the pockets of rich ore is intimately associated with iron and manganese oxides.³ In view of the fact that the unaltered sulphides had not been encoun-

¹ McCaskey, H. D., Notes on some gold deposits of Alabama: Bull. U. S. Geol. Survey No. 340, 1908, p. 36.

² Lindgren, Waldemar, The Annie Laurie mine, Piute County, Utah: Bull. U. S. Geol. Survey No. 285, 1906, pp. 87-90.

³ Emmons, W. H., and Garrey, G. H., Notes on the Manhattan district: Bull. U. S. Geol. Survey No. 303, 1907, pp. 87-90.

tered when the mines were visited, the character of the primary ore is unknown to me, nor is it certain that all the deposits have decreased in value below the oxidized zone.

BULLFROG, NEVADA.

In the Bullfrog district, Nevada,¹ the principal deposits are fissure veins in rhyolite. The minerals include pyrite, quartz, and manganese calcite. Enough manganese is present in the calcite to stain much of the oxidized ore chocolate-brown or black. No placers are developed. The outcrops were comparatively poor, but good ore was encountered within a few feet of the surface, and some of the deposits were worked by open cut. Some of the ore deposits decrease in value below the 400-foot level, where ore carrying less than \$5 a ton is encountered. Since the ore above this level carried many times this value, it appears that there has been a secondary concentration by surface waters and that the rich ore is related to the present topographic surface.

In these ores, as in other manganeseiferous gold ores in calcite gangue, secondary deposition of gold has not been carried far below the surface.

GOLD CIRCLE, NEVADA.

The deposits of the Midas or Gold Circle district, Nevada,² are in late Tertiary rhyolites. The lodes are replacement veins and sheeted zones and carry considerably more gold than silver by value. In the oxidized zone some of the ore is rich, but the sulphides are comparatively regular in value and give no evidence of extensive enrichment. Some oxidized ore shoots appear to have been increased in value by the removal of substances more soluble than gold. The minerals are chiefly quartz and pyrite. The oxidized zone contains seams of very rich gold ore, composed of manganese, limonite, kaolin, and soft hydrous silica.

DELAMAR MINE, NEVADA.

The Delamar mine, in southeast Nevada, is in quartzite which is cut by acidic porphyry dikes. The ore body, described by S. F. Emmons,³ is related to a strong zone of fracturing, which strikes with the quartzite but dips about 75°, or nearly at right angles to the dip of the quartzite. The ore is in shoots or zones of crushed quartzite. The chief ore body, which is, roughly speaking, a long and compara-

¹ Ransome, F. L., Emmons, W. H., and Garrey, G. H., *Geology and ore deposits of the Bullfrog district, Nevada*: Bull. U. S. Geol. Survey No. 407, 1910.

² Emmons, W. H., *A reconnaissance of some mining camps in Elko, Lander, and Eureka counties, Nev.*: Bull. U. S. Geol. Survey No. 408, 1910, pp. 48-57.

³ Emmons, S. F., *The Delamar and the Horn Silver mines*: Trans. Am. Inst. Min. Eng., vol. 31, 1901, pp. 658-675.

tively thin, nearly upright cylinder, is divided into four parts by a dike of quartz porphyry and a more basic dike, which cross nearly at right angles in the ore body. The ore follows the line of intersection of the two dikes rather closely. The ore at the bottom of the mine consists of quartz and pyrite, which fill fractures in the altered quartzite. Where the dikes cross in the ore body the light-colored dike appears to be continuous, but notwithstanding this the line of the dark dike across the light one is generally marked by a slight stain of manganese dioxide, which, as stated by Emmons, is characteristic of the "black" dike and perhaps gives it that name.

Oxidation extends as far down as the tenth level. The ore that has been found below that level is too low in grade to pay for mining. The gold ore carries silver and some copper. The tenor in gold increased from the surface downward to about the seventh level, although the values were not evenly distributed. Some lots of ore ran as high as 30 ounces per ton, and the richer parts of the mine averaged from \$30 to \$70 per ton. At the tenth level they had decreased to \$4 or \$5 per ton.

EXPOSED TREASURE MINE, CALIFORNIA.

The Exposed Treasure mine,¹ near Mohave, Cal., has produced considerable gold and silver. It is in an area of granitic rocks cut by quartz porphyry and capped by rhyolite. The lodes are probably Tertiary. The Exposed Treasure vein dips about 45° E. and is a sheeted brecciated zone. Considerable fissuring has taken place since the ore was deposited.

The lodes are continuous and many of them are of great width, some being 40 feet and more from wall to wall, but the pay streaks, from 4 to 15 feet in width, lie in well-defined shoots and overlapping sheets or lenses. It is noteworthy that only those shoots or lenses which now reach the surface contained important quantities of calcite and manganese dioxide.

The oxidized ores contain much manganese dioxide, the concentrates carrying 12 per cent. In the altered oxidized ore are kernels of ore containing pyrite, chalcopyrite, galena, and sphalerite, and these are richer in the precious metals than the altered friable ore. As observed by De Kalb—

The altered ore bore manifest signs of extensive leaching, and where it had become almost completely decolorized by the removal of iron the precious-metal contents had nearly disappeared, and such ore never contained copper except in the form of chrysocolla.

The absence of sulphides in all the [oxidized] ores, except in the cherty skeletons and in the undecomposed kernels of hard ore, was very complete. The mill concentrates (150 into 1) had an average composition of SiO₂, 30; FeO, 37; * * * and

¹ De Kalb, Courtenay, *Geology of the Exposed Treasure lode, Mojave, Cal.*: *Trans. Am. Inst. Min. Eng.*, vol. 38, 1908, pp. 310-319.

MnO₂, 12 per cent. These concentrates never contained more than 1.5 per cent of sulphur. * * *

In the lower friable siliceous ores the ratio of gold to silver was as 1 to 12, while in the upper mangano-calcitic ores the ratio was as 1 to 72. Assays of gold scale and of coarse gold panned out from all parts of the mine showed a remarkably uniform alloy of 1 part of gold to 0.461 part of silver. The silver in the upper portion of the mine was present almost wholly in the form of silver chloride.

On the assumption, from the evidence, that the abundance of chlorides would prevent the leaching out of silver and its reconcentration below water level, and that the ferric and cupric sulphates would have abstracted large quantities of the gold, which would be redeposited lower down, together with the copper in the form of secondary enrichments, it was natural to predict an ore below permanent water rich in these metals and relatively lean in silver. It would be difficult to conceive a nicer justification of theory than that which was afforded when development at length extended below water level. The ore consisted of a hard bluish-gray mass of original chert-cemented breccia, recemented by quartz, with partial replacement of the granite and quartz porphyry by silica, heavily impregnated with sulphides, among which were considerable quantities of chalcopyrite, some bornite, and some covellite. The gold content of the ore had increased 150 per cent above the average in the friable siliceous ores on the upper levels, and the ratio of the gold to silver was as 1 to 2.

BODIE, CALIFORNIA.

The deposits of Bodie, Cal., are east of the Sierra, near the State line. They are not of the California type but are associated with andesite and belong to the late Tertiary group so extensively developed in Nevada. R. P. McLaughlin¹ has described the most important mines. The lodes are fissure veins in andesite. Nearly all strike northward and are approximately parallel. The ore carries about equal amounts of gold and silver. The deposits are developed extensively to a depth of 500 feet below the surface. One shaft is 1,000 feet, another 1,200 feet deep. Outcrops of encouraging value are rare. Almost without exception the veins have failed to carry pay ore beyond 500 feet below the surface; but above this depth occur large, rich ore bodies, which, according to McLaughlin, carry ore worth as much as \$400 a ton. Faulting and displacement are probably of later date than the period of vein formation. Some of the oxidized ore carries manganese dioxide. It is "loose and clayey in texture and carries some silver to the exclusion of gold."

LITTLE BURRO MOUNTAINS, NEW MEXICO.

The Little Burro Mountains, just north of Tyrone, N. Mex., consist of pre-Cambrian granitic rocks overlain by Cretaceous sediments and later eruptive rocks. These are partly buried by Tertiary (?) lavas and intruded by rhyolitic or trachytic stocks.² Some gold veins in

¹ McLaughlin, R. P., *Geology of the Bodie district, Cal.*: Min. and Sci. Press, vol. 94, 1907, p. 796.

² Paige, Sidney, *Metalliferous ore deposits near the Burro Mountains, Grant County, N. Mex.*: Bull. U. S. Geol. Survey No. 470, 1911, p. 132.

this region carry abundant manganese dioxide and chlorides. The ore minerals include chalcopyrite, pyrite, sphalerite, and galena.¹ Zinc blende is conspicuous, and the ores assay 10.2 per cent zinc.

According to Paige²—

The Wyman vein has been worked over a distance of about 500 feet and not below a depth of 110 feet. The richest returns came from the part above a depth of 40 feet. Silver chloride and gold furnished the values in these upper levels. Zinc and copper are reported to have increased as greater depth was attained and gold and silver to have fallen to \$3 to \$5 a ton. In the upper portion of the vein much of the ore is reported to have assayed \$200 to the ton.

MARYSVILLE, MONTANA.

Marysville, Mont., about 18 miles northwest of Helena, is in an area of pre-Cambrian sandstones, shales, and limestones that are intruded by quartz diorite and by later porphyry dikes.² The deposits are mainly in fault fissures in sedimentary rocks. Placers are developed. The Drumlummon mine has been developed for about 3,000 feet horizontally and to a depth of 1,600 feet, but no ore was found below the 1,000-foot level.

According to Weed³—

In general, it may be said that all the veins of the district carry rich ores in bonanzas and ore shoots within the first 200 feet from the surface, but that in depth the ores rapidly decrease in value until the vein is no longer workable. It may also be said that the ore shoots were well defined and the intervening vein matter barren and unworkable. The pitch of the ore shoots conforms to the usual habit, dipping to the right when looking down the dip of the vein. The ores consist of sulphides and sulphantimonides of silver, with gold aggregating 60 per cent of the total value. In the upper levels the ore is somewhat oxidized and in the ore shoots of the Drumlummon mine carried extremely high values.

Mr. Adolph Knopf⁴ informs me that the gangue in depth is highly calcitic and that the rich ores of native gold that are found at and near the surface are associated with abundant manganese oxides.

SUMMIT DISTRICT, COLORADO.

The Summit district is southwest of Alamosa, Colo., near the Rio Grande—Conejos county line. According to R. C. Hills,⁵ the metal-bearing rocks are near the middle of the Tertiary eruptive series of south and southwest Colorado. The associated rocks are andesites, trachytes, rhyolites, and other eruptives; but, unlike the eruptives

¹ Paige, Sidney, Metalliferous ore deposits near the Burro Mountains, Grant County, N. Mex.: Bull. U. S. Geol. Survey No. 470, 1911, p. 136.

² Barrell, Joseph, Geology of the Marysville mining district, Montana: Prof. Paper U. S. Geol. Survey No. 57, 1907.

³ Weed, W. H., Gold mines of the Marysville district, Montana: Bull. U. S. Geol. Survey No. 213, 1903, p. 70.

⁴ Oral communication.

⁵ Hills, R. C., Ore deposits of Summit district, Rio Grande County, Colo.: Proc. Colorado Sci. Soc., vol. 1, 1883, pp. 20-26.

of most Tertiary districts in this province, these rocks appear to have been closely compressed and form a series which, as shown in Hills's sketches, is probably isoclinal. Some features of the ore deposits are puzzling, but, whatever their genesis, they illustrate very clearly the theory of enrichment—a fact which was fully recognized by Hills as long ago as 1883.

The ore bodies, so far as exposed, are rudely tabular and approximately vertical. The ore is chiefly quartz and pyrite but contains some enargite, galena, sphalerite, and other minerals.

Although Hills mentions brown oxides at several places, he does not say that they are mangiferous. Raymond¹ states that the oxides include those of purplish hue.

Placers appear to be of subordinate importance. The mineralized matter may be separated into three divisions—(1) the impoverished zone near the apex, (2) the zone of rich and partly oxidized ore, and (3) the zone of low-grade sulphides. The zone of impoverishment includes the outcrops of all but two of the lodes and it extends downward to a depth of 50 feet or more. The zone of incompletely oxidized ore extends to a depth varying from a few feet to 300 feet. In this zone the quartz is colored dark brown by oxides and the more highly auriferous material is characterized by an abundance of brown oxide. The gold in this ore carries only about 0.025 silver. According to Hills, all the bonanzas were confined to this zone. In some places gold appears in disseminated form, in innumerable small grains so aggregated as to resemble a continuous sheet of metal. Locally the grains unite and form flat nuggets 1 ounce or more in weight. According to Hills, the occurrence of this richer material is confined to the immediate vicinity of a central channel which has been filled with earthy matter, fragments of rock, and iron oxides. Some of the rich seams of gold powder have been introduced into fractures which cut barite. Below the rich and partly oxidized ore the primary sulphides appear to have been unworkable under conditions then existing. There is, however, in three mines a concentration of silver at greater depth than that of the gold bonanzas. Hills ascribes the two rich outcropping ore bodies, which are exceptional in this district, to intense kaolinization on either side of them, causing the country rock to be much more readily eroded than the extremely hard quartz. This consequently remained considerably above the general surface, forming a precipitous ridge that was, as he explains, protected from solution, which went on more vigorously below, in the places where snow and water accumulated.

¹ Raymond, R. W., *Mines and mining west of the Rocky Mountains*, vol. 10, 1875, p. 329.

BOHEMIA MINING DISTRICT, OREGON.

The Bohemia mining district of Oregon is an area of andesitic lavas and tuffs, which are cut by dacite porphyry and probably by basalt.¹ The deposits are fissure veins composed of sphalerite, pyrite, a little galena, and very little chalcopyrite, with a gangue of quartz, altered country rocks, and some calcite. According to MacDonald²—

Some of the veins were brecciated after they were filled, and as a result oxygenated surface waters were able to percolate downward along the fractured zone. The ores were thus oxidized and sulphides leached out to depths of 100 to 300 feet, the depth depending on the degree of brecciation and the rate of erosion. The gold occurred as threads and filaments included in the pyrite. The pyrite was leached away, leaving the relatively insoluble gold and some iron oxide occupying a part of the small cavity left in the vein material. This process brought about an association of free gold with iron-stained spongy quartz and enriched the ore by leaching out the valueless sulphides. It also rendered the ore soft and porous, so that it is much more cheaply mined and milled than the unaltered ore.

Small local enrichments of free gold occur at the junctions of fissures, pyrite being abundant at these junctions, as shown by the mass of iron oxide left. It is probable that the smaller particles of gold were dissolved from the upper parts of the vein * * * and were precipitated by the local masses of pyrite below.

Some secondary sulphides were observed, but these are of no commercial value. They consist of pyrite crystals deposited in cracks in primary pyrite and of very small masses of sphalerite and galena. Other secondary minerals noted were calcite and, rarely, cerusite.

SAN JUAN REGION, COLORADO.

The gold deposits of the San Juan region, Colorado, including those near Telluride, Silverton, and Ouray, are, as shown by Ransome,³ of varied character. They are mainly Tertiary, probably middle Tertiary, but have nevertheless undergone very extensive erosion. The region is moist, its altitude is 8,000 to 14,000 feet above sea level, and much of it has been glaciated. The prevailing rocks are volcanic tuffs, breccias, and flows and intrusive igneous rocks of intermediate or acidic composition.

In this elevated area the ground is frozen much of the year, and the rapid erosion is due largely to mechanical disintegration. Secular decay or oxidation of the ores, according to Ransome, is not as a rule very extensive and is at some places negligible. Purington has pointed out, however, that the outcrops of the San Juan lodes, are, in general, of lower grade than the ore a few feet below the surface, possibly by reason of the migration of gold in suspension. Many of

¹ Diller, J. S., The Bohemia mining region of western Oregon: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, pp. 7-64. MacDonald, D. F., Notes on the Bohemia mining district, Oreg.: Bull. U. S. Geol. Survey No. 380, 1909, p. 80.

² MacDonald, D. F., op. cit., p. 82.

³ Ransome, F. L., A report on the economic geology of the Silverton quadrangle, Colorado: Bull. U. S. Geol. Survey No. 182, 1901. Purington, C. W., Preliminary report on the mining industries of the Telluride quadrangle, Colorado: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, p. 745. Purington, C. W., Woods, T. H., and Doveton, G. D., The Camp Bird mine, Ouray, Colo.: Trans. Am. Inst. Min. Eng., vol. 23, 1903, pp. 499-550.

the lodes are tight and do not appear to offer favorable conditions for downward migration of waters. The country is well drained and chlorine is probably not abundant in the mine waters. The conditions for deep-seated enrichment are therefore not particularly favorable, although some concentration has taken place locally by the leaching and removal of the less valuable materials from the ore. The workable ore appears to be mainly of primary origin.

At some places the gangue includes manganiferous minerals. There is some evidence that gold was transported to a moderate extent. As Ransome points out,¹ black oxide of manganese occurs (in 1901) in the deepest workings in the Tomboy and Camp Bird mines and usually indicates good ore. These little sheets of rich, dark manganiferous ore, which fill postmineral fractures, Ransome regards as later than the general mass of the ore. It is reasonable to suppose that they represent deposition from solutions which dissolved gold in the upper portion of the lode, where ferric salts prevail, and which, in the presence of manganese, were able to transport their load to greater depths, but which, coming into contact with pyrite, were ultimately reduced and forced to give up their gold when, through the oxidation of pyrite, ferrous sulphate had been formed.

In the Yankee Girl mine, between Silverton and Ouray, the ores down to about 200 feet from the surface were mainly silver and lead, galena and pyrite being the principal minerals. The ore below this zone is composed mainly of stromeyerite, bornite, chalcocite, and some gray copper and barite, yielding about 30 per cent of copper and little or no lead. In depths below 600 or 700 feet the ore in this and adjoining mines is said to have gradually turned into a low-grade pyritous ore, which was of too low grade to work at a profit, so that the mines were closed. The ores in the copper-bearing zone had been exceptionally rich, carrying several thousand ounces of silver to the ton in carload lots.²

CRIPPLE CREEK, COLORADO.

The gold deposits of Cripple Creek, Colo., are fissure veins and replacement deposits in volcanic breccia, in alkali-rich and other Tertiary intrusive rocks, and in granite. The fissures, according to Lindgren and Ransome,³ were formed at about the time of the intrusion of the associated basic dikes and represent a late phase of volcanic activity. The deposits are probably of middle or late Tertiary age and were formed relatively near the surface by hot ascending waters. Calaverite is the chief primary constituent;

¹ Ransome, F. L., *op. cit.*, p. 101.

² Emmons, S. F., The secondary enrichment of ore deposits, in Pošepný, Franz, *The genesis of ore deposits*, 1902, pp. 451-452.

³ Lindgren, Waldemar, and Ransome, F. L., *Geology and gold deposits of the Cripple Creek district, Colorado*: Prof. Paper U. S. Geol. Survey No. 54, 1903, pp. 167-168.

native gold is rarely present in the unoxidized ores. Pyrite is widely distributed; tetrahedrite, stibnite, sphalerite, and molybdenite are sparingly present. The gangue is quartz, fluorite, adularia, carbonates (including rhodochrosite), some sulphates, and other minerals. Some of the deposits were workable at the surface, but the placers formed are relatively unimportant. Although rhodochrosite is subordinate in amount, the highly fractured country rock contains appreciable manganese ($0.2 \pm$ per cent.). According to Lindgren and Ransome, the processes of oxidation were attended by the formation of kaolin, hydrous silica, and oxides of iron and manganese. Manganese oxides are commonly present in the oxidized zone¹ and, according to Penrose, form nodules in the Pharmacist and Summit mines. They result from the alteration of rhodochrosite, manganiferous calcite, or other minerals and are generally distributed in the oxidized zone as stains in cracks and fissures.² During oxidation manganese is greatly concentrated in the seams of the rock. In general, the lower part of the zone of oxidation is above water level and is usually less than 200 feet below the surface. In some places silver has been completely leached from the oxidized ores. Horn silver has not been noted.

Whether a slight enrichment of gold has taken place in the oxidized zone is not easy to demonstrate. Lindgren and Ransome are inclined to the belief that the oxidized zone as a whole is somewhat richer than the corresponding telluride zone.³ The trivial enrichment in this zone may have resulted from the removal of some constituents of the primary ore.

If gold was dissolved in the Cripple Creek deposits it was precipitated again at practically the same horizon, for in these deposits the zone in which solution takes place is rich. The ground is open, providing paths for downward-circulating waters, but although the ore-bearing complex is very pervious to water it is surrounded by impervious rocks. After the volcanic rocks had been drained in mining the flow of water was comparatively small. Lindgren and Ransome have compared the volcanic complex to a "sponge in a cup." As shown by them, the conditions were unfavorable for the circulation of atmospheric water—a fact which had an important bearing on their conclusion that the ores had been formed by magmatic waters. In the absence of a circulation the gold could not be transported. A check to this reasoning with respect to a downward circulation is the fact that in the porous, brecciated mass, filled with stagnant water, the oxidation extended downward to a depth generally less than 200 feet, and even in this zone residual sulphides are present. If the

¹ Penrose, R. A. F., Mining geology of the Cripple Creek district, Colorado: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, p. 123.

² Lindgren, Waldemar, and Ransome, F. L., op. cit., p. 123.

³ Idem, p. 203

solutions did not carry oxygen downward it would be supposed that they could not carry gold; and even if the gold had been dissolved at the higher levels, in the absence of a circulation it could not descend. There is some evidence which may be interpreted as an indication that the gold migrated laterally, or possibly that it was precipitated essentially in place from cold solutions. Richard Pearce¹ has recorded analyses of oxidized and unoxidized ore. The material for the analyses was taken from a section drawn clear across the two different portions of the specimen. The analyses show that the oxidized ore carries 14.58 ounces of gold per ton, or 2.34 ounces more gold than the unoxidized ore, and that all the silver has been leached out. In ore so rich such a concentration may result merely from leaching out of the substances other than gold; but, on the other hand, the analyses of the altered rock indicate that little leaching of the silicate minerals has taken place and that the oxidized portion was originally richer than the unoxidized, or else that some gold had been added. Since 0.27 per cent of manganese dioxide is present in the oxidized ore, while none is reported in the unoxidized ore, it appears that manganese dioxide was added in the process of secondary alteration, and it is possible that the same solutions added gold and iron. J. W. Finch² regards some of the gold as secondary.

If the gold was dissolved in the Cripple Creek "sponge," it may have been precipitated in the stagnant solutions where they were in contact with pyrite. In the absence of a downward circulation of water such lateral migration would be possible.

The results of oxidation processes are described by Lindgren and Ransome³ as follows:

Thorough oxidizing decomposition will destroy the original structure of this vein. In sheeted lodes with many small parallel fissures and joints the latter may become effaced and the lode appears as a homogeneous brown soft mass. In other cases a central seam may be retained and usually appears as a streak of soft, more or less impure kaolin; in other cases it may be filled by white compact alunite, more rarely by jasperoid or opaline silica. Crusts of comb quartz, if originally present, lie included in the clayey seams, but neither the original fluorite nor the carbonates are ordinarily preserved. Very rich oxidized ore sometimes fills the central cavities of the lode like a thick brown mud of limonite, kaolin, and quartz sand and easily flows out when the vein is opened.

It should not be inferred, however, that where channels are large and open the rich, gold-bearing brown mud is necessarily a deposit from solution. It may have been carried down in suspension; for similar rich mud, with 2 ounces of gold per ton, was found on the

¹ Pearce, Richard, Further notes on Cripple Creek district: *Proc. Colorado Sci. Soc.*, vol. 4, 1896, pp. 11-16.

² Finch, J. W., The circulation of underground aqueous solutions and the deposition of lode ores: *Proc. Colorado Sci. Soc.*, vol. 7, 1904, pp. 193-252.

³ Lindgren, Waldemar, and Ransome, F. L., *op. cit.*, p. 199.

floor of the twelfth level of the Gold Coin mine, after it had been filled with water and allowed to stand.

It thus appears that the conditions at Cripple Creek, which are somewhat puzzling, may be rationally explained if it is noted that the downward migration of gold requires not only solution and precipitation but also circulation, and that the conditions for circulation here were peculiarly unfavorable. The facts show also that a relatively rapid circulation is required to carry dissolved gold far below the zone of mixed oxides and sulphides.

GEORGETOWN QUADRANGLE, COLORADO.

The auriferous deposits of the Georgetown quadrangle, Colorado, are mainly at Idaho Springs and in the Empire district, although some are developed near Georgetown, in the area of the silver-lead deposits. As shown by Spurr and Garrey,¹ the gold lodes are probably of later age than the silver-lead deposits. They cut the crystalline schists and the Tertiary porphyries but are genetically related to alkali-rich intrusive rocks of middle or late Tertiary age. They carry pyrite, chalcopyrite, chalcocite, quartz, adularia, and gold and minor amounts of barite, fluorite, telluride, and other minerals. Carbonates of iron, magnesium, lime, and manganese occur but are relatively rare. The deposits generally contain some galena and sphalerite. In many of the mines the ore averages 1 to 2 ounces of gold and 20 to 40 ounces of silver per ton. The lodes are usually oxidized at the surface and from 15 to 70 feet downward. They have yielded some moderately productive placers. In several mines the oxidized ore is much richer than the average ore. Below the zone of oxidation secondary chalcopyrite and chalcocite prevail for several hundred feet from the surface but decrease at greater depth. There is an important enrichment of gold and silver, coincident with the occurrence of the copper minerals. As stated by Spurr and Garrey²—

In the mines mentioned a portion of the copper which has contributed to the enrichment of the original sulphides has been derived from the oxidized zone, but it seems unlikely that this has been the case with the gold and silver, which, like the enriched superficial portions of the argentiferous veins, must have been derived from the overlying portions of the lodes which are now eroded. * * *

On the whole, the strongest evidence of the reworking of the ores by surface waters is afforded by markedly cupriferous ores. * * * Apart from this, however, and from the probable partial concentration of galena near the surface in some mines, the evidence of rearrangement of the ores by descending waters is in general not nearly so great as in the Georgetown district, and such reworking has probably taken place to a considerably less extent.

¹ Spurr, J. E., and Garrey, G. H., *Economic geology of the Georgetown quadrangle, Colorado*: Prof. Paper U. S. Geol. Survey No 63, 1908, pp. 99-101.

² *Idem*, p. 149.

GOLDFIELD, NEVADA.

The ledges of Goldfield are in middle or late Tertiary rocks and, according to Ransome,¹ were probably deposited within 1,000 feet of the Tertiary surface. Ransome states convincingly the hypothesis that these deposits were formed by hot ascending solutions which mingled with descending sulphate water that contained oxygen derived from the air. Although the deposits are probably the most remarkable bonanzas of native gold ores carrying little silver which have yet been discovered, it does not appear that they have been very greatly enriched since they were deposited, for, as remarked by Ransome, it is difficult to harmonize the extent and intensity of alunitization in the gold ores with the hypothesis that the ores were formed by the oxidation and enrichment of lean deposits during erosion. The mine waters are rich in sulphates and, judging from the geographic position of the deposits, probably carry chlorides. Manganese dioxide is practically unknown in these ores, which in this respect differ from the ores at Tonapah and from a great many other Tertiary deposits of the Great Basin province. No workable placer deposits have been discovered; yet, notwithstanding the fact that several hundred feet of vein matter may have been removed from these deposits since they were formed, there is little reason to suppose that much gold has migrated into the existing bonanzas from above. The gold is very finely divided and could easily have been scattered if it had been eroded with the ledges. Analyses of deposits elsewhere that were formed close to the surface by ascending hot waters show that few of them carry much gold. The zone of maximum deposition is lower down, for as soon as the ascending hot waters are contaminated by ferrous sulphate from the surface the gold they contain must be precipitated.

The evidence offered at Goldfield is not out of harmony with the conclusion that in the absence of manganese gold is not readily transported in mine waters.

PHILIPSBURG, MONTANA.

The Philipsburg quadrangle is an area of sedimentary rocks ranging in age from pre-Cambrian to late Cretaceous, with intrusions of granodiorite and related rocks, probably belonging to the same period of intrusion as that of the Butte quartz monzonite and other batholiths in Montana. The most important ore deposits in this quadrangle are those of the Granite-Bimetallic and Cable mines.

The Granite-Bimetallic mine² is working a strong fissure vein in granodiorite, which carries chiefly silver but also an important

¹ Ransome, F. L., The geology and ore deposits of Goldfield, Nev.: Prof. Paper U. S. Geol. Survey No. 66, 1909, p. 174.

² Emmons, W. H., and Calkins, F. C., Geology and ore deposits of the Philipsburg quadrangle, Montana: Prof. Paper U. S. Geol. Survey No. 78 (in press).

amount of gold. There is conclusive paragenetic evidence of the enrichment of silver below the water level, and the rich silver ore carries also more gold than the low-grade silver ore in the bottom of the mine. The outcrop of this deposit carried some silver but very little gold, and after the discovery the location was allowed to lapse by reason of the small assay returns from the gossan. Richer ore with secondary cerargyrite, native silver, and ruby silver in cracks across the older sulphides appeared in considerable amount 200 to 400 feet below the surface and extended to depths of 800 or 900 feet. The shoot of high-grade ore, which extended for about a mile along the strike of the deposit, followed, in a broad way, the present rugged surface. The gangue is rich in manganese. No pyrrhotite was noted, but zinc blende is abundant at several places in the primary ore below the richer sulphides. Some migration of gold has undoubtedly taken place. No associated placers have been developed.

At the Cable mine¹ the deposits are included in a long, thin block of limestone, in contact on either side with quartz monzonite. The principal minerals are calcite, quartz, pyrrhotite, pyrite, magnetite, and chalcopyrite, with chlorite, muscovite, and other silicates. At one or two places small traces of manganese dioxide have been noted in the oxidized ore, but it is very much less abundant than in the deposits of the Granite-Bimetallic type. This deposit yielded important placers. Good ore was found at or very near the surface and, according to the best obtainable data, the tenor increased somewhat for a short distance below the surface. Some concentration has taken place by the removal of calcite and other valueless material more rapidly than gold, but there is no evidence of enrichment in gold below the water table. The conditions indicate that the gold has not been extensively transported since the deposit was formed.

NEIHART, MONTANA.

The Neihart district, Montana,² is a region of Archean granite and pre-Cambrian quartzite with intrusive diorite and porphyry. The deposits are silver-bearing fissure veins, which in depth carry considerable sphalerite, pyrite, and galena. Superficial alteration is not marked, and there are no great zones of carbonates and oxidized ore. The Broadwater vein is partly oxidized to a depth of 170 feet and in pipes and fissures to even greater depths. Below the oxidized ore were large bodies of secondary silver sulphides, consisting of polybasite, pyrargyrite, pearceite, and "sooty sulphide ores," much

¹ Emmons, W. H., and Calkins, F. C., *Geology and ore deposits of the Phillipsburg quadrangle, Mont.*: Prof. Paper U. S. Geol. Survey No. 78 (in press).

² Weed, W. H., *Geology of the Little Belt Mountains, Montana*: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, p. 271.

of this ore running 200 to 1,000 ounces per ton. The rich silver minerals occur in cracks in the primary ore or coat fragments of that ore. Manganese oxides abound.

The zones of impoverishment, of enrichment, and of unaltered primary sulphides recognized in the case of the copper veins are clearly present here, though the uppermost is of limited extent, and the zones are not so sharply or definitely separated from one another as they are in copper deposits, owing to the later fissuring of the vein filling allowing the secondary enrichment to be mixed with the unaltered sulphides. * * * In the Neihart ores polybasite seems to show an alteration to pyrrargyrite and pyrite, and the former in turn changes to native silver in the upper zone.¹

TINTIC DISTRICT, UTAH.

The Tintic district² is in central Utah, in a mountainous area that rises some 8,000 feet above the sea and nearly 4,000 feet above the plains. The temperature is moderate, the climate is dry, and most of the streams that drain the area disappear in the loose material of the desert. The area is occupied by a thick series of Paleozoic quartzites, slates, limestones, and sandstones, which are overlain by Tertiary rhyolite and andesite and intruded by monzonite and basalt. The andesite flows are intruded by great masses of monzonite and by basalt dikes, and an andesite equivalent to the monzonite caps the rhyolite.³ These rocks are folded and extensively fractured and faulted. The late history of the region may be briefly stated as follows:⁴

1. Elevation of the region, with folding of the Paleozoic sedimentary rocks.

2. Erosion, which began with the Mesozoic uplift and continued into the Tertiary, producing a surface with greater relief than that of to-day.

3. Tertiary volcanic activity, the earlier rhyolitic lava filling deep canyons, on the slopes of which talus was cemented by the lava and the later andesite lava flows, largely rejuvenating the deeply eroded mountain range.

4. Fissuring and ore deposition in the more compact igneous and sedimentary rocks.

5. Erosion, by which great masses of igneous rock have been removed, with only slight changes in the topography of the limestone ridges, which had been buried by the lavas.

The ore deposits are (1) large fractured zones in sedimentary rocks, chiefly in the limestone; (2) fissure veins in igneous rocks; and (3) contact-metamorphic deposits in sedimentary rocks near intrusive igneous rocks, mainly in the limestone near monzonite.⁵

¹ Weed, W. H., The enrichment of gold and silver veins: Trans. Am. Inst. Min. Eng., vol. 30, 1901, p. 446.

² Tower, G. W., Jr., and Smith, G. O., Geology and mining industry of the Tintic district, Utah: Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1899, pp. 603-767.

³ Idem, p. 657.

⁴ Smith, G. O., written communication.

⁵ Tower, G. W., Jr., and Smith, G. O., op. cit., p. 722.

In igneous rocks the water level is encountered 200 to 700 feet below the surface; above this the ore is almost completely oxidized. In limestone the water level is much deeper and oxidized ore extends 1,800 feet or even 2,000 feet ¹ below the surface.

The primary ore minerals of the deposits include pyrite, galena, enargite, chalcopyrite, and tennantite. Sphalerite is rare in this district,² and pyrrhotite is not mentioned. The gangue includes quartz, barite, carbonates, chalcedony, and gypsum. Oxidation products include limonite, hematite, anglesite, cerusite, minium, melaconite (?), native sulphur, jarosite, copper carbonates, cuprite, native copper, and a large number of rare arsenic compounds which have resulted from the decomposition of enargite. Argentite, stephanite, and native silver are somewhat rare. Cerargyrite is more abundant. Chalcocite and bornite become increasingly abundant in the lower parts of the oxidized zone. Some quartz is clearly secondary.³

The metals, named in the order of their importance up to 1898, are silver, lead, gold, and copper. With increasing depth silver and lead have decreased relatively and copper has become more abundant, especially in the Centennial Eureka mine. In 1909 the yield of copper was 6,000,000 pounds, the district ranking in copper production the thirteenth in the United States. According to Graton,⁴ secondary sulphide deposition seems to have played but little part in the distribution of values.

A remarkable feature of the district is the great depth at which the oxidized ores are found. They are deeper, indeed, than the submerged oxidized ore at Bisbee, Ariz., where the deep secondary zone is related to a pre-Comanche erosion surface rather than to the present one. At Tintic, however, the ores are probably early Miocene.⁵ Since they were formed, great masses of igneous rocks, according to Smith,⁶ have been removed by erosion.

GEORGETOWN, COLORADO (SILVER DEPOSITS).

The Georgetown district, Colorado, is a rugged area of gneisses and schists, which are cut by Tertiary intrusives of varied composition. Several thousand feet of overlying rocks, according to Spurr, Garrey, and Ball,⁷ have been eroded since the veins were formed. Some of

¹ Lindgren, Waldemar, oral communication.

² Tower, G. W., jr., and Smith, G. O., *op. cit.*, pp. 686, 703.

³ *Idem*, p. 693.

⁴ Graton, L. C., *Mineral Resources U. S. for 1906*, U. S. Geol. Survey, 1907, p. 407; *idem* for 1907, pt. 1, U. S. Geol. Survey, 1908, p. 618.

⁵ Smith, G. O., written communication.

⁶ Smith, G. O., *The mineral crest, or the hydrostatic level attained by the ore-depositing solutions in certain mining districts of the Great Salt Lake basin* (discussion of W. P. Jenney's paper): *Trans. Am. Inst. Min. Eng.*, vol. 33, 1903, pp. 1060-1062.

⁷ Spurr, J. E., Garrey, G. H., and Ball, S. H., *Economic geology of the Georgetown quadrangle, Colorado*: Prof. Paper U. S. Geol. Survey No. 63, 1908, p. 145.

the valuable minerals of the eroded portions have been redeposited in the portions remaining.

The zone of complete oxidation is 5 feet to 40 feet deep. In the silver-lead deposits the minerals on the lower levels are chiefly zinc blende and galena, with pyrite, chalcopyrite, and a little silver and gold. Rich soft sulphides are found, especially along cracks and watercourses, and are of secondary origin, having evidently been concentrated from the leaner ore by descending waters. They occur down to considerable depths from the surface but in decreasing quantity. The older and typically more massive ores in which they have formed contain usually very much less silver and also less gold. For example, secondary sulphides which contain 200 to 300 ounces of silver have been formed by this concentration process from primary ore which carries only 20 to 30 ounces.

Below the zone where soft secondary sulphides occur and irregularly overlapping the lower portion of this zone the rich ores contain polybasite, argentiferous tetrahedrite, and ruby silver, better crystallized and more massive than the pulverulent sulphides but also subsequent in origin to the massive galena-blende ore. These richer ores diminish in quantity as depth increases, though gradually and irregularly, so that the lower portion of the veins contains relatively less silver and lead. The best ore in most veins has been found in the uppermost 500 feet, although good ore extends locally down to 700 or 800 feet, and in the Colorado Central and to a minor extent in other veins down to a thousand feet or more.¹

BRECKENRIDGE, COLORADO.

The fundamental rocks in the Breckenridge region, Colorado, as stated by Ransome,² are granites, pegmatites, gneisses, and schists of pre-Cambrian age. The oldest sedimentary rocks, which rest directly on the pre-Cambrian, are red sandstones and shales, supposed to be of Triassic or of Permian age. Apparently conformable above them is the Dakota quartzite with some gray shale, which is overlain by a thick formation of Upper Cretaceous shales. The sediments and the pre-Cambrian rocks are intruded by monzonitic porphyries, which occur mainly as sills.

The primary deposits, according to Ransome, include veins of a zinc-lead-silver-gold series, stockworks and veins of a gold-silver-lead series, and the gold veins of Farncomb Hill. The placers of the district have been important producers of gold.

The Wellington veins afford the chief examples of the zinc-lead-silver-gold series, the filling of which consists mainly of sulphides, quartz in notable quantity being absent from most of them. In the Wellington mine the principal constituents of the ore are galena, sphalerite, and pyrite in various proportions. Even along the out-

¹ Spurr, J. E., Garrey, G. H., and Ball, S. H., *Economic geology of the Georgetown quadrangle, Colorado*: Prof. Paper U. S. Geol. Survey No. 63, 1908, p. 144.

² Ransome, F. L., *Geology and ore deposits of the Breckenridge district, Colorado*: Prof. Paper U. S. Geol. Survey No. 75, 1911, pp. 25-26.

crops of the veins of the Wellington group most of the deposits carry galena in the claylike product resulting from thorough oxidation, and the change to essentially sulphide ore generally takes place at depths of less than 300 feet. The depth of the oxidized zone, however, varies, being greatest in general near the crest of the ridge in which the ore bodies occur and least along the lower slopes.

The normal sequence from the surface down appears to be (1) a soft, heavy yellowish claylike ore consisting largely of earthy cerusite and containing residual nodules of galena; (2) a lead-silver ore in which the galena is only in part oxidized, while the pyrite has been for the most part changed to limonite and the sphalerite altered to smithsonite and limonite, with removal of much of the zinc in solution; and finally (3) a lead-silver-zinc ore in which galena predominates and in which the early stages of oxidation are indicated by the formation of a little spongy smithsonite, or "dry bone," as the miners call it, at the expense of the zinc blende.¹

A notable feature of the oxidized ores is their general high content of lead and silver as compared with the sulphides beneath. In some mines this difference was so great that their owners after extracting ore profitably to the base of the oxidized zone found the sulphides of so low a grade that they abandoned work. Here and there the oxidized ores also show a noteworthy concentration of gold even where the sulphide ores below contain only negligible quantities of that metal. Thus in the Helen mine, on the south side of French Gulch, some gold ore was found near the surface, although the latest and deepest workings have exposed nothing but a little sphaleritic zinc ore. In the Juventa mine, which produced some good oxidized ore to a depth of 200 feet and was then abandoned, wire gold is said to have been found.

It is believed that a large proportion of the galena is the result of downward concentration by atmospheric water, which, after percolating with comparative rapidity through the oxidized zone to the local ground-water level, thence moved more slowly down through the sulphides, emerging finally along the bottoms of the main valleys. Although some sphalerite is younger than other sphalerite, it is not surely a deposit of sulphate waters. Iron is deposited as an impure siderite in veinlets traversing the sulphide ores or as the lining of vugs in these ores. Additional iron issues in springs after performing its work of enrichment. Silver, according to Ransome, generally keeps close to the lead, and gold appears to accumulate in the zone of oxidation rather than at greater depths. In general, profitable operations did not extend below 300 or 350 feet in depth.

The Farncomb Hill veins immediately below the zone of oxidation consist of pyrite, chalcopyrite, sphalerite, galena, calcite, and gold. Some wire gold has been found in the unoxidized vein material but

¹Ransome, F. L., *Geology and ore deposits of the Breckenridge district, Colorado*: Prof. Paper U. S. Geol. Survey No. 75, 1911, p. 134.

not far below the zone of general weathering, and the principal concentration of the native metal is connected with oxidation.

Says Ransome:¹

Two intimately related processes appear to have been effective in enriching these veins. These, in the order of their action at one place, were (1) enrichment by solutions depositing calcite, galena, gold, and perhaps sphalerite below the zone of oxidation and (2) enrichment in the zone of oxidation by solution and redeposition of the gold.

It is clear that during the weathering of these veins the gold was acted on by some very efficient solvent, for otherwise it would be impossible to account for the large crystalline masses of gold characteristic of the hill. These could not have been deposited in the veins as part of their original fillings, for they are limited to the oxidized zone, and the once very productive placers below the hill show that this zone can not coincide with originally rich upper portions of the veins. Evidently the original tops of the veins have been eroded away and their contained gold in part has been strewn along the ravines and down the main valleys and in part has seeped down in solution along the fissures and been deposited in segregated masses. Active as solution must have been, erosion apparently was overtaking it; at least the richness of the placers proves that the gold was not carried down and redeposited fast enough to escape the forces of mechanical disintegration.

Ransome states that a manganiferous carbonate occurs in the Wire Patch mine of Farncomb Hill, and sphalerite from the Silver vein showed some manganese, but some oxidized material from the Reveille showed none. It is not known whether the mine water carried appreciable chloride, but the experiments of Brokaw (p. 126) indicate that under some conditions a faint trace of chlorine is effective in the solution of gold. In connection with the abrupt impoverishment in depth, attention should be called also to the mineral association of these ores and to experiments previously cited showing the rapidity with which acid solutions are reduced by sphalerite and auriferous chloride solutions are neutralized by calcite. With both calcite and sphalerite the conditions for rapid precipitation of gold are very favorable.

CREEDE, COLORADO.

The deposits of Creede, Colo.,² are strong fissure veins in rhyolites and rhyolite breccias. One of them extends for nearly 2 miles along the strike and is developed from 1,000 to 1,400 feet below the surface. The rocks show great postmineral fracturing. The primary deposits consist of pyrite, zinc blende, galena, and other minerals in a gangue of manganiferous amethystine quartz with barite, chlorite, and some adularia. The most valuable deposits of silver, the most important metal in this district, were found 200 to 700 feet below the surface, but wire silver was mined at depths below

¹ Ransome, F. L., *Geology and ore deposits of the Breckenridge district, Colorado*: Prof. Paper U. S. Geol. Survey No. 75, 1911, p. 169.

² Emmons, W. H., and Larsen, E. S., *A preliminary report on the geology and ore deposits of Creede, Colo.*: Bull. U. S. Geol. Survey No. 530, 1913, pp. 42-65.

1,000 feet. Some of the richest silver ore is evidently secondary and consists of red jasper with abundant native silver.

Stringers of black manganese oxide cutting unoxidized sulphide ore extend downward to depths of nearly 1,000 feet. In the Happy Thought mine, on the Amethyst vein, between levels 6 and 7, a body of partly oxidized ore composed of galena, zinc blende, copper carbonates, cerusite, and anglesite carries a conspicuous amount of manganese dioxide, which coats the copper sulphides and occurs in fractures cutting the partially oxidized ores. A considerable body of this ore yielded \$20 a ton in gold, which indicates notable enrichment, since the average content of gold in the mine is about \$2 a ton.

RICO, COLORADO.

The rocks of Rico, Colo.,¹ include Paleozoic limestones, sandstones, and shales, which are cut by dikes and laccolithic sheets of monzonite porphyry. The ore deposits include fissure veins and ribbon-like masses, which make out in limestone from the fissure veins where the latter cross the contact of limestone with overlying shale. In the lower levels of the mines, some 200 feet below the "contacts," the ore is mainly quartz, pyrite, and chalcopyrite. In raising on the veins rhodochrosite, galena, sphalerite, and tetrahedrite become prominent. Upward, toward the "contact," the proportion of metallic minerals steadily increases, and the ore becomes much richer in gold and silver. Irregular nuggets and sheets of argentite, polybasite, and stephanite are found. Occasionally pyrargyrite, proustite, and native silver appear. Rhodochrosite, on the other hand, is almost never found in the zone immediately below the shale, although it is abundant in the vein lower down.

LAKE CITY, COLORADO.

The silver-lead deposits of Lake City,² in southwestern Colorado, are in an area of Tertiary flows and tuffs of the Silverton volcanic series, which consists of andesites, rhyolites, latites, and basalts. These are cut by intrusions of rhyolite and quartz latite and by quartz monzonite porphyries.

The deposits are narrow fissure veins and some fill conjugate fissures. Their vertical range, according to Irving and Bancroft, is over 5,000 feet, and in their lower levels the primary minerals are chiefly quartz, galena, zinc blende, and pyrite. The ores formed at shallower depths include also tetrahedrite, rhodochrosite, barite, and jasperoid. The mineralization was probably effected by solutions

¹ Ransome, F. L., The ore deposits of the Rico Mountains, Colo.: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, pp. 229-398. Farish, J. B., The ore deposits of Newman Hill: Proc. Colorado Sci. Soc., vol. 4, 1892, pp. 151-164.

² Irving, J. D., and Bancroft, Howland, Geology and ore deposits near Lake City, Colo.: Bull. U. S. Geol. Survey No. 478, 1911.

connected genetically with the quartz monzonite intrusion or with some closely related deeper rock.

Many of the lodes are greatly fractured, and the conditions in this rugged country are favorable to deep circulation. Erosion is rapid, however, and the oxidized zone is not deep, extending generally not more than 100 or 200 feet below the surface. This zone contains iron oxides and sulphates, copper carbonates, and considerable anglesite, with some native copper and silver. Cerusite is not abundant.

The secondary silver minerals are chiefly pyrrargyrite and galena but include some chalcocite and possibly proustite. Native gold, though not common in the oxidized ore, is present in the upper part of the zone of sulphide enrichment. Of the total production of all metals having a value above \$7,000,000, about one-sixth is gold. The table showing the metal production of the district indicates a fairly constant proportion in the annual production of gold and silver. The abundance of sphalerite in the primary ore would seem to favor relatively rapid precipitation of the metals by descending solutions. Some of the secondary ore shoots, however, have a wide vertical range, but such a distribution of the richer ore has been greatly favored by the very rugged topography. At the Moro mine the secondary sulphides are found nearly 500 feet vertically below the surface, but the slope is between 30° and 40° and the circulation is presumably vigorous. The reactions precipitating the metals seem to have been relatively rapid. As stated by Irving and Bancroft,¹ zinc blende has very generally exerted an extensive effect in reprecipitating the downward-moving sulphates in the form of secondary sulphides.

ASPEN, COLORADO.

The Aspen district, Colorado,² is an area of granite overlain by Paleozoic limestones, sandstones, and shales, which are intruded by dikes and sills of diorite porphyry and quartz porphyry. Structurally the district is a fault mosaic of folded beds and the principal ore deposits are replacements of limestones in and along fault fissures. The primary ore deposition was effected by ascending magmatic waters and took place in a relatively brief period, but according to Spurr³ it had three successive stages—(1) barite veins, (2) silver sulphides, sulphantimonites, and sulpharsenites, (3) galena and blende—each stage being preceded by slight fracturing of the rocks. The maximum deposition was below shale beds.

Near the surface the ores occur as oxides, sulphates, and carbonates, mixed with sulphides, from which they are evidently

¹ Irving, J. D., and Bancroft, Howland, *Geology and ore deposits near Lake City, Colo.*: Bull. U. S. Geol. Survey No. 478, 1911, p. 64.

² Spurr, J. E., *Geology of the Aspen mining district, Colorado*: Mon. U. S. Geol. Survey, vol. 31, 1898.

³ Spurr, J. E., *Ore deposition at Aspen, Colorado*: Econ. Geology, vol. 4, 1909, p. 303.

derived. The principal ore in these upper zones consists of earthy carbonates and sulphates, chiefly of lead (cerusite and anglesite). Among the oxides hematite and limonite are very common, and the red oxides of copper and lead (cuprite and minium) occur in blotches in the oxidized ores, usually indicating the presence of silver. With increase in distance from the surface the oxides, sulphates, and carbonates disappear and give place to pure sulphides. Argentiferous galena and blende are abundant in the deeper ore and other sulphides are of less frequent occurrence. Pyrite and chalcopyrite, with occasional bornite, are also found. Tetrahedrite and tennantite are common and contain a large proportion of silver sulphide. The gangue is quartz and barite.

In the Mollie Gibson and Smuggler mines there is much polybasite, which generally occurs in flesh-colored barite, the color being due to a small amount of iron oxide. Along watercourses the polybasite is reduced to native silver, so that the ore consists of pink and gray barite bound together by irregular wires and masses of silver. As this process is attended by some loss of bulk, the ore also becomes much jointed and loses cohesion.

Spurr states that native silver is abundant to depths of at least 900 feet in deposits where the water level stood about 300 feet. Generally the native silver is found near silver sulphides and in fractures that are later than primary mineralization. Nearly all the larger bodies of native silver are on the side of the vein which is formed by shale and some of them are wholly within the shale wall.

LEADVILLE, COLORADO.

Leadville, Colo.,¹ is in an area of Paleozoic limestones, quartzites, and shales that are intruded by dikes and sills of acidic porphyries. Normal faulting has taken place on an extensive scale. The climate is moist, the altitude high. The most important deposits are found in Carboniferous limestone at or near its contact with an overlying porphyry, which is generally the "White porphyry." Thus the ores constitute a sort of sheet, the upper surface of which, being formed by the base of the porphyry sheet, is comparatively regular, while the lower surface is ill defined and irregular, there being a gradual transition from ore to limestone, the ore extending to varying depths below the surface, occupying in places the entire thickness of the Leadville ("Blue") limestone. Other deposits include, however, steeply dipping veins, some of them in fault fissures, and irregular masses or sheets in limestone near the "Gray" or other porphyries.

The ore that is most abundant and that is economically by far the most important is argentiferous galena and its secondary products,

¹ Emmons, S. F., *Geology and mining industry of Leadville, Colo.*: Mon. U. S. Geol. Survey, vol. 12, 1888. Emmons, S. F., and Irving, J. D., *The Downtown district of Leadville, Colo.*: Bull. U. S. Geol. Survey No. 320, 1907.

cerusite, or carbonate of lead, and cerargyrite, or chloride of silver. Lead is also found as anglesite and pyromorphite and occasionally as oxide in the form of litharge or, more rarely, of minium. Silver occurs frequently as chloriodide and very rarely in the native state. The gangue minerals include quartz, chert, barite, and clay, the clay being frequently charged with iron and manganese oxides or with sulphates.

A common alteration product of mixed pyrite and galena, a product that is associated in considerable quantity with the ore bodies, is "basic ferric sulphate," an ocherous substance of somewhat uniform appearance but of varying composition, mainly a mixture of jarosite, or yellow vitriol, and hydrated basic ferric sulphate, with more or less anglesite and pyromorphite.

Gold occurs in the native state, generally in extremely small flakes or leaflets. It is also said to have been found in the filiform state in galena.

Accessory minerals are zinc blende, calamine, arsenic (probably as sulphide), antimony (probably as sulphide), wulfenite, copper (carbonate and silicate), and bismuth sulphide.

In depth the ores consist of pyrite, sphalerite, and galena in fairly equal amounts, with some chalcopyrite and other minerals.

Nodules of galena surrounded by lead carbonates are locally numerous in the oxidized zone. Several of these nodules have been assayed, and the sulphide has been found to carry about six times as much silver as the surrounding carbonate shell.¹

Emmons² states that gold exists in the limestone ores only in traces. In certain veins of sulphide ores below the porphyry contacts, according to G. Montague Butler,³ some small masses of sphaleritic mangiferous ores are very rich in gold. A picked sample assayed 8 ounces per ton. Silver is found in the oxidized ores mainly as chloride. It is a generalization of the miners of the region, according to Emmons,⁴ that rich silver-chloride ores are likely to accompany manganese. As suggested by him and also on a previous page of this paper (p. 120), it is possible that the agency of manganese in the generation of free chlorine is important in connection with the precipitation of silver chloride under some conditions.

In general, silver values diminish with depth. The upper contact bodies as a whole were richest in silver; the "second contact" bodies were slightly lower in tenor; and at lower horizons the ore is of distinctly low grade.⁵

¹ Ricketts, L. D., *The ores of Leadville*, Princeton, 1883, p. 37.

² Emmons, S. F., *op. cit.*, p. 545.

³ Butler, G. M., *Some recent developments at Leadville: Econ. Geology*, vol. 7, 1912, p. 318.

⁴ Emmons, S. F., *op. cit.*, p. 562.

⁵ Emmons, S. F., and Irving, J. D., *op. cit.*, p. 34.

Very recently large bodies of iron-stained smithsonite have been found in the oxidized zones below lead-carbonate ores. Some of these were formerly supposed to be iron-stained limestone. A. A. Blow¹ maintained that sphalerite is deposited by downward-moving waters just in advance of oxidation, and in this S. F. Emmons² appears to concur. Some small veinlets of galena are found also in sulphide ore just below the oxidized zone.

Of considerable interest are some small fractures in the quartzite at a lower horizon, which, as Mr. Emmons informed me, very commonly carry small amounts of high-grade manganiferous gold ore. This ore he regarded as a deposit from descending waters.

EUREKA, NEVADA.

The Eureka district,³ in eastern Nevada, is an area of Paleozoic quartzites, limestones, and shales, which were intruded, probably in late Mesozoic time, by granite, granite porphyry, and quartz porphyry. Subsequently, probably in the Tertiary period, the sedimentary rocks were intruded by great igneous bodies of andesitic composition and covered in places by rhyolite and basalt. The beds are thrown into open folds and the dominant structure is a fault mosaic, the principal faults being of the normal type.

The ores occur in sedimentary rocks belonging to the Cambrian, Silurian, and Devonian periods. Through a section involving 17,000 feet of deformed strata they have been deposited in sufficiently large bodies to encourage mining exploration.

According to Curtis,⁴ the ore bodies are chiefly replacements of fractured limestones and include lodes, stocks, and bedding-plane deposits. The elevation of the region is from 6,000 to 7,500 feet above the sea, but neighboring peaks are higher. The climate is arid and the water level deep. On a section by Curtis through the Jackson, Eureka Consolidated, and Richmond shafts⁵ the water level is shown at a depth of 500 feet in the Jackson and from 1,000 to 1,200 feet in the Richmond shaft.

The larger ore bodies, according to Curtis, are capped by caves or are in some way connected with caves or fissures, developed by solution, and the fall of rock into the openings has caused further fissuring. Since this action took place the ore has in many places been redistributed by the flow of underground waters. The ore above the water level is composed principally of the minerals galena,

¹ Blow, A. A., The geology and ore deposits of Iron Hill, Leadville, Colo.: Trans. Am. Inst. Min. Eng., vol. 18, 1890, p. 172.

² Emmons, S. F., The secondary enrichment of ore deposits, in Pošepný, Franz, The genesis of ore deposits, 1902, p. 440.

³ Hague, Arnold, Geology of the Eureka district, Nevada: Mon. U. S. Geol. Survey, vol. 20, 1892.

⁴ Curtis, J. S., Silver-lead deposits of Eureka, Nev.: Mon. U. S. Geol. Survey, vol. 7, 1884.

⁵ Idem, Pl. III.

anglesite, cerusite, mimetite, and wulfenite, with very little quartz and calcite, the gangue being for the most part hydrated oxide of iron. The ore carries also considerable gold and silver and some zinc, which occurs probably as carbonate and silicate. The ore below the water level is composed chiefly of pyrite, arsenopyrite, galena, zinc blende, and a few other sulphides, as well as silver and gold. According to Curtis the oxidized ore grades into the sulphide ore. At some places altered ore is found below the water level, and Curtis supposed that the water level was recently elevated. The development of mimetite, a chloro-arsenate of lead, as stalactites in the oxidized zone, is of interest. Zinc blende is found to some extent in upper parts of the mines, according to Curtis, and is of common occurrence in the lower workings in connection with pyrite and galena. The deposits had produced over \$60,000,000 in silver and gold and 225,000 tons of lead in 1882. More recently enormous bodies of low-grade ferruginous gold ore have been mined in the shattered and altered limestones that surround the old silver stopes.

PIOCHE, NEVADA.

The deposits of Pioche, Nev.,¹ are in a faulted area of quartzites, limestones, and shales which are cut by an acidic porphyry intrusive. The most important deposits, some of which have been very productive, are near the intrusives. They fill fissure veins in the quartzite and limestone and the ores are more abundantly developed in the quartzite. They were stoped at the surface and averaged about \$150 a ton. Ores consisting of silver chloride and sulphide and lead carbonate extended to water level, where the oxidized ore gave place to sulphides and large amounts of zinc also entered. At this depth, according to Pack,² the vein was generally strong and persistent, but no valuable deposits were in sight when the property was abandoned, even though prospecting had been very extensive.

In recent years some other large productive deposits have been developed. Of these I have no exact knowledge.

TONOPAH, NEVADA.

The deposits at Tonopah, Nev., are silver-gold replacement veins in andesite. They are of middle or late Tertiary age but possibly somewhat older than the Comstock lode. Placers are not developed. The primary ore, according to Spurr,³ is composed of quartz, adularia, sericite, and carbonates of lime, magnesia, iron, and manganese, with argentite, stephanite, polybasite, chalcopyrite, pyrite, galena,

¹ Pack, F. J., *Geology of Pioche, Nev., and vicinity*: School of Mines Quart., vol. 27, 1906, pp. 285-312, 365-386.

² Idem, p. 372.

³ Spurr, J. E., *Geology of the Tonopah mining district, Nevada*: Prof. Paper U. S. Geol. Survey No. 42, 1905, p. 90.

silver selenide, and gold in an undetermined form. Pyrrhotite is not listed. According to Spurr, a little zinc sulphide is present, but Burgess¹ does not list sphalerite as a vein mineral.

The zone of oxidation extends to greater depth in the more highly fractured places, and for this reason the brittle and more broken lodes are more deeply oxidized than the wall rock. The Mizpah vein is for the most part oxidized to a depth of 700 feet. Standing ground water is lacking. The oxidized ore contains limonite and manganese dioxide, with plentiful horn silver and some bromides and iodides of silver. The so-called oxidized ore from the outcrop down is, according to Spurr, a mixture of original sulphides (and selenides), together with secondary sulphides, chlorides, and oxides. At a depth of 500 feet (in the Montana Tonopah mine) good crystals of argentite, polybasite, and chalcopyrite have been formed freely in cracks and druses of the sulphide ore. These minerals are later than the massive ore, but it can not be shown that they were not deposited upon it by ascending waters. The deposit of dark ruby silver (pyrargyrite) is different, however, for it is formed in cracks in the oxidized ore, and some argentite fringes minute particles of horn silver as if secondary to it. The evidence, therefore, as stated by Spurr, favors the view that these secondary sulphides in the oxidized zone originated from descending surface waters, and probably part of the sulphides in druses in the sulphide ore have a similar origin.

The waters that descend through the oxidized zone carry sulphates and chlorides, and "wad" is plentiful; but judging from the fairly constant proportion of gold to silver (about 1 to 100 by weight) there has been little selective migration of gold and silver during oxidation, although the vein has been enriched to some degree by downward penetration of minerals leached from the outcrop as it was eroded. The rich ore shoots, though partly oxidized, seem to be in the main original without thorough rearrangement. According to Spurr, this may be ascribed in part to the relatively scanty supply of water in this arid region.

COMSTOCK LODE, NEVADA.

The Comstock lode² is a broad fault zone in late Tertiary rocks. The ore shoots occur here and there in this zone, which is developed more than 4,000 feet below the surface.

¹ Burgess, J. A., The halogen salts of silver and associated minerals at Tonopah, Nev.: *Econ. Geology*, vol. 6, 1911, pp. 13-21.

² King, Clarence, The Comstock lode, in Hague, J. D., *Mining Industry*: U. S. Geol. Expl. 40th Par., vol. 3, 1870, pp. 11-96. Church, J. A., *The Comstock lode*, New York, 1879. Becker, G. F., *Geology of the Comstock lode and the Washoe district*: Mon. U. S. Geol. Survey, vol. 3, 1882. Reid, J. A., *The structure and genesis of the Comstock lode*: Bull. Dept. Geology Univ. California, vol. 4, 1905, pp. 177-199.

King¹ says:

Quartz forms the only gangue in the Comstock lode. Those small masses of carbonate of lime which occur, intermingled with quartz, in the Gold Hill and Hale & Norcross lower levels are rather to be considered an included mineral of accidental occurrence than as a true gangue. With the exception of small quantities of silver minerals contained in the clay sheets where they are placed in close contact with the bonanza, the whole silver tenor of the lode is contained in the bodies of quartz. The ore itself is composed of native gold, native silver, silver glance, stephanite, rich galena, occasional pyrargyrite, horn silver, and, with extreme rarity, sternbergite. Intimately associated with these occur iron and copper pyrites and zinc blende. Of these, pyrargyrite and horn silver are rarities; polybasite and sternbergite, in recognizable crystals, occupy a few scattered localities; stephanite, in defined crystallizations, has been found in nearly every bonanza, but the main body of the ore is a confused semi-crystallized association of native gold and silver, vitreous silver ore, rich galena, copper and iron pyrites, and zinc blende.

In general the bonanza ore is pretty uniformly disseminated through the quartz. Large, solid accumulations are rarely found. The silver minerals ordinarily lie in masses about the size of a hen's egg. In the central portions of bonanzas there is usually a somewhat denser arrangement of ore. It is evident, from the manner in which the ore itself is broken and dislocated, that the dynamic action which powdered the quartz occurred after it was charged with ore.

Since the period of crushing additional charges of quartz and ore have been introduced into the fissure to a small extent. In a few places, as in the 800-foot level of the Yellow Jacket mine, broken fragments of quartz, themselves containing ore, have been re cemented by sheets of stephanite which have penetrated the cracks, and over the stephanite a secondary growth of quartz crystals has taken place, and these quartz crystals themselves are again coated with a fine varnish of silica.²

Analyses of ore from the lower workings of the Savage and Kentuck mines (1869) gave zinc sulphide 1.75 and 0.13 per cent, respectively. Ores from "middle depths" of the California and Ophir mines gave 12.85 and 14.45 per cent of zinc.

Like King, Becker notes that there were clearly two periods of movement, one before the deposition of the primary ore and one after it. The later movement, mainly parallel to the lode, gave conditions for an active circulation of water after the primary deposition. According to Becker,³ "it is possible that the seams of rich ore in the great bonanza represent a deposition posterior to the final cessation of movement," and "it is also by no means impossible that some of the richer ores have been redeposited, forming at the expense of surrounding bodies of lower grade." As already remarked, analysis of the vadose water of the Comstock shows that it contains both gold

¹ King, Clarence, *op. cit.*, p. 79.

² *Idem*, p. 81.

³ Becker, G. F., *op. cit.*, p. 273.

and silver. It is noteworthy that this water contains much manganese, presumably as sulphate. Some associated placers were developed, but they are of very subordinate value compared with that of the lode. Oxidation extended downward to a depth of 500 feet. According to King,¹ "a zone of manganese oxide occupies the entire length of the lode from the outcrop 200 feet down." The upper part of this manganiferous zone was not of high grade in general, especially in its uppermost portions. The longitudinal projections² show that many of the stopes carried from below stop some distance below the surface.

Von Richthofen (quoted by Becker) says that "the proportion of gold to silver decreased during the early period of working the lode but is now (1865) on the increase again." Presumably silver at the very surface was leached more rapidly than gold. The vadose waters, as shown by Reid,³ are rich in sulphate, and his analyses, as well as others, show the presence of chlorides in appreciable amounts. The conditions appear to have been favorable for the migration of both silver and gold in the upper levels, even in the comparatively short time that has elapsed since the primary ores were deposited. The bonanza ore below consisted largely of stephanite, polybasite, argentite, and other minerals.

I have no detailed descriptions of the character and position of the richest ores, but Eliot Lord⁴ states that the "Big Bonanza," an enormously rich ore body in the lode, extended below the fifteenth level. Possibly some of the richer ore bodies extended still deeper, but it is well known that rich ore was more abundant in the upper than in the lower levels. The deposits in the upper levels yielded, according to Richthofen, from \$70 to \$107 a ton, whereas in later years the average value of the ore was not more than \$37 a ton.

It thus appears that the evidence of the Comstock lode, from the surface down, is favorable to the hypothesis that extensive solution and deposition of gold and silver have taken place.

The proportion of gold to silver was presumably higher near the surface and in the lower part of the lode than in the middle part. When Richthofen made his report he estimated that to the close of 1865 the lode had produced \$15,250,000 in gold and \$32,750,000 in silver (gold equals 47 per cent of the silver); whereas Becker reports the amount recovered from 1865 to 1881 as \$87,121,988 in gold and \$105,548,157 in silver (gold equals 83 per cent of the silver).

The relation of "horn silver" to the surface is different from that shown in "chloride mines." According to King,⁵ silver chloride is

¹ King, Clarence, *op. cit.*, p. 75.

² Becker, G. F., *op. cit.*, atlas sheets X-XII.

³ Reid, J. A., *op. cit.*

⁴ Lord, Elliot, *Comstock mining and miners: Mon. U. S. Geol. Survey, vol. 4, 1883, p. 311.*

⁵ King, Clarence, *op. cit.*, p. 82.

accidental, although rare small crystals were found at the outcrop of the Gold Hill group and elsewhere.

ST. EUGENE MINE, MOYIE, BRITISH COLUMBIA.

The St. Eugene mine is in the mountainous country near Lake Moyie, British Columbia. This region is situated at a moderately high latitude and is therefore of particular interest, since the workable ore shows a relation to the present topography that appears to indicate appreciable secondary concentration. The deposit affords one of the best examples of sulphide enrichment that I have noted in Canada. The following data, from a report by S. J. Schofield,¹ are supplied through the courtesy of Mr. R. W. Brock, director of the Geological Survey of Canada.

The claims operated by the principal company include two veins, which strike east and dip 70° S. They are about 600 feet apart and the developments extend through a vertical range of 2,100 feet. The lower workings are over 100 feet below the level of Lake Moyie. The two main veins are connected by a series of important cross veins, most of which meet the main veins at acute angles. These cross fissures, the spaces between which are not uniform, are locally termed "avenues." Most of the ore bodies are in the fractured and folded area along and between the main veins, and in places large ore shoots occur near or at the places where the avenues meet the main veins. Very little displacement was observed along the main fissures, although the strata are slightly folded or bent near the fissures. The country rocks consist of argillaceous quartzites and purer heavy-bedded quartzites of the pre-Creston, the oldest known subdivision of the Purcell series, which here form the axis and eastern limb of an anticline. The ore bodies are associated with the massive purer quartzites of the pre-Creston formation. The ore consists of galena, both fine and coarse grained, associated in places with zinc blende. The gangue, which is small in amount, consists of garnet, anthophyllite (a variety of amphibole), and a little quartz, the last mineral being very prominent where the vein pinches in the argillaceous quartzites. Locally the wall rock in the immediate vicinity of the ore bodies shows strong metamorphism by the development of garnet and anthophyllite.

A vertical projection or stope sheet supplied by Mr. Brock shows workings along the hill for 4,900 feet. The slope of the hill is about 25°. Thirteen tunnels, one above another, are driven to the ore zone. Some of these tunnels are 2,000 to 3,000 feet long, but all the stopes appear to be within 1,500 feet of the surface, as measured on a level, or somewhat less than 800 feet from the nearest points

¹ Schofield, S. J., *Reconnaissance in east Kootenay: Summ. Rept. Geol. Survey Canada for 1911, 1912*, pp. 158-164.

on the surface. The distance from the surface to which most of the ore shoots were followed is practically uniform. Below the level of the lake the workings did not extend so deep. At depth the fissures tighten, the ore becomes less concentrated, and zinc blende becomes relatively more abundant, so that the ore is no longer of commercial grade. At the junction of the "avenues" and main vein and nearer the surface were large bodies of clean shipping ore. Elsewhere the ore was concentrating ore. Mr. Brock informs me that a similar relationship between present surface and the ore bodies is noticeable at many points in the Slocan.

COBALT, ONTARIO.

Cobalt,¹ in the Nipissing district, northern Ontario, is on the great ancient peneplain which extends over much of Ontario and the surrounding region. The country is hilly, but the relief is not great. The climate is cold and moderately moist. The recent glaciation is clearly evident, but drift is generally thin or absent.

The basement rocks are the Keewatin series, a complex of metamorphosed basic igneous rocks, usually known as greenstones, which includes also some rock of sedimentary origin. The eroded surface of the Keewatin is overlain by Huronian conglomerates, graywacke, and other metamorphosed sedimentary rocks. A quartz diabase sill some 500 feet thick was intruded into both Huronian and Keewatin rocks. This dips southward at an angle of about 17°.

The deposits are short, narrow fissure veins, very numerous and rich. They are found in the Huronian, in the diabase, and in the Keewatin, but the more productive deposits are in the Huronian near the diabase sill, or they were below the footwall of the sill before the sill was eroded. The deposits are probably genetically related to the diabase intrusive, and the fractures have been assumed to represent cooling cracks formed in connection with the intrusion of the diabase. Postmineral fracturing and faulting have taken place extensively.

The principal sulphides of earlier age include smaltite, cobaltite, chloanthite, and bismuth sulphide, with some arsenopyrite and tetrahedrite. Pyrite, galena, and sphalerite are present in the wall rock near the vein. The silver occurs as native metal, proustite, pyrargyrite, dyscrasite, and argentite. The gangue minerals include calcite and quartz.

The zone of oxidation is exceedingly shallow or altogether absent, but certain exceptionally rich superficial deposits, a few feet thick, are directly connected with the zone of weathering. This is called the "nugget horizon," and in it the smaltite and cobaltite have been

¹ Miller, W. G., The cobalt-nickel arsenides and silver deposits of Temiskaming, 2d ed.: Rept. Ontario Bur. Mines, vol. 16, pt. 2, 1908.

largely altered to secondary minerals or leached out altogether. In this zone "cobalt bloom" and "nickel bloom" are characteristic minerals.

Extending downward 200 or 300 feet or more below the surface are rich silver minerals, largely in veinlets in earlier sulphides. The minerals of the veinlets include native silver, argentite, and calcite. The change from rich to low-grade ore is very abrupt, both in depth and on the strike. Van Hise¹ and Emmons² have attributed these richer silver ores to processes of sulphide enrichment, but Miller³ is inclined to the belief that this feature of the genesis has been too much emphasized.

ROSSLAND, BRITISH COLUMBIA.

Rossland, British Columbia, is in the Trail Creek district, a short distance north of the international boundary. The country is glaciated and the altitude of the principal deposits is about 3,400 feet above sea level. The rocks exposed⁴ include Carboniferous limestone, quartzites, and shales with interbedded tuffs, ash beds, and lavas. Above this series are volcanic agglomerates and lavas. Intruding these rocks are masses of monzonite, granodiorite, nepheline syenite, etc.

The principal deposits are fissure fillings and replacement veins, fractured zones, and impregnations. The most important lodes have steep dips. These lodes are intricately faulted and many of the faults follow or are followed by basic dikes. The deposits carry commercial amounts of copper and silver.

The gangue minerals are biotite, quartz, calcite, tourmaline, amphibole, chlorite, and garnet; the sulphides include pyrrhotite, chalcopyrite, pyrite, arsenopyrite, marcasite, gold, and other minerals.

In certain gold-bearing quartz veins the gold and chalcopyrite are intimately related and there is a notable concentration of gold near the surface.

The ore shoots in the cupriferous precious-metal lodes extend downward 50 to 500 feet. One shoot averaged 150 feet long and 56 feet thick and was worked downward 500 feet. There is very little oxidation above these deposits and no secondary chalcocite zone. The values of shipments decrease as greater depths are reached, but this decrease may be due to improvement of conditions which permits profitable extraction of lower-grade material.

¹ Van Hise, C. R., The ore deposits of the Cobalt district, Ontario. Jour. Canadian Min. Inst., vol. 10, 1907, pp. 45-53.

² Emmons, S. F., Cobalt district, Ontario, in Bain, H. F., and others, Types of ore deposits, San Francisco, 1911, pp. 140-156.

³ Miller, W. G., Notes on the Cobalt area: Eng. and Min. Jour., vol. 92, 1911, pp. 645-649.

⁴ Brock, R. W., Preliminary report on the Rossland, B. C., mining district, Geol. Survey Canada, 1906.

CŒUR D'ALENE, IDAHO (LEAD-SILVER DEPOSITS).

The geology and ore deposits of the Cœur d'Alene mining district, Idaho, are described by Ransome and Calkins.¹ The district is an area of pre-Cambrian quartzites and siliceous slates, which are intruded by large masses of monzonite and related rocks. Some contact metamorphism has taken place and certain of the ore bodies are of the garnet sulphide type, but the principal deposits are wide lead-silver lodes free from garnet.

The country is extensively faulted, but the lodes are not along the major faults. The ores were formed partly by filling open spaces, but largely by replacement along zones of fissuring or shearing. The deposits, which have a vertical range of 4,000 feet, were probably formed under several thousand feet of rock which has since been removed.

The ore minerals are galena, pyrite, chalcopyrite, sphalerite, and subordinate pyrrhotite, with some argentiferous tetrahedrite and stibnite. Siderite is the most abundant gangue mineral, with subordinate quartz and a little barite. The ores carry about 8 per cent lead and 4 ounces silver to the ton.

Ransome² says:

Although the mineralogical character of the large lead-silver deposits exhibits great uniformity, some of the ore bodies are known to change their composition with increase of depth. No evidence has been found, however, that in any way connects the observed changes with the descent of solutions from the zone of oxidation. Such variations as occur are apparently original and not due to secondary enrichment from above.

In the process of oxidation cerusite develops from galena without any visible intermediate product. The change is not a direct replacement of the sulphur of carbonic anhydride, but the galena is irregularly corroded by the oxidizing solutions and cerusite crystals are deposited in the cavities thus formed. In other words, the lead itself is somewhat immobile during the change from sulphide to carbonate. The various minerals of the oxidized ores are still forming and make up soft earthy masses in which no sequence of crystallization is apparent. It is not known, for example, whether pyromorphite, like cerusite, forms directly from galena or whether it is derived from some oxysalt of lead.

The small quantity of sphalerite formerly in the ores which have undergone oxidation has left no recognizable trace of its presence.

¹ Ransome, F. L., and Calkins, F. C., The geology and ore deposits of the Cœur d'Alene district, Idaho: Prof. Paper U. S. Geol. Survey No. 62, 1908.

² Idem, p. 112.

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